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REPORT MDA 903-82-G-0051.82-4.0002

ECONOMIC PRODUCTION RATE STUDY

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MARCH 1983

Prepared for:
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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: MDA 903-82-G-0051.82-4.0002	2. GOVT ACCESSION NO: AD-A127 380
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Economic Production Rate Study	5. TYPE OF REPORT & PERIOD COVERED: 1 July 1982 - 15 March 1983
	6. PERFORMING ORG. REPORT NUMBER: ADTECH Report No. 31413.02
7. AUTHOR(s): Downing, E.J.; Roesler, G.E.; McGovern, W.M.	8. CONTRACT OR GRANT NUMBER(s): MDA 903-82-G-0051.82-4.0002 Task Order No. 82-4
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Advanced Technology, Inc., Airport Plaza, Suite 500, 2711 Jefferson Davis Hwy, Arlington, VA 22202	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: David D. Acker, Defense Systems Management College, Ft. Belvoir, VA 22060	12. REPORT DATE: 15 March 1983
	13. NUMBER OF PAGES: 112
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release. Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for public release. Distribution unlimited.

18. SUPPLEMENTARY NOTES

N/A

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

EPR, production, unit cost, program stability, acquisition, defense acquisition management, economic production rate, economic procurement rate, A-10 Aircraft, A-6E Aircraft, TOW Missile, Abrams M-1 Tank, Bradley Fighting Vehicle System.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report defines and discusses economic production rate and economic procurement rate. Examples are presented to clarify the definition. Models are presented which relate changes in unit cost to changes in production rate. The procurement rates of five defense acquisition programs are analyzed with respect to their economic procurement rates.

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

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Acknowledgment

The authors gratefully acknowledge the valuable assistance of Professor David D. Acker of the Defense Systems Management College who provided guidance, support, and a critical review to this study. Others, too numerous to mention by name, but whose organizations are listed below, provided insight into the subject area and reviewed the study drafts. Their inclusion here does not indicate their approval of the study results, but rather their sincere effort to make the results accurate and useful.

Department of Defense
- Office of Under Secretary of Defense (Research and Engineering)
- Product Engineering Services Office
- Defense Systems Management College

U.S. Army
- Army Procurement Research Office
- Army Materiel Development and Readiness Command
- Army Missile Command
- Abrams M-1 Tank Program Office
- Bradley Fighting Vehicle System Program Office
- TOW Missile Program Office

U.S. Air Force
- Air Force Systems Command
- A-10 Aircraft Program Office

U.S. Navy
- Hdqtrs. Naval Material Command
- Naval Air Systems Command
- Naval Electronic Systems Command
- A-6E Aircraft Program office

General Dynamics Corporation
General Electric Company
Grumman Aerospace Corporation
John M. Cockerham & Associates, Inc.

EXECUTIVE SUMMARY

The Department of Defense Acquisition Improvement Program Action Number 7 stresses the need to reduce unit cost by planning for and maintaining economical rates of production. This Action can be implemented if planning begins early enough in a program to influence the many contractor decisions that will determine the economic production rate (EPR). As early as the Demonstration/Validation Phase, decisions on production quanitites and production funds will largely determine the EPR so that, during the Production and Deployment Phase, emphasis shifts to the efficient use of the factors of production. Early planning should be directed toward selecting a realistic, supportable level of production as well as contingency plans for higher and lower production levels. During the Production and Deployment Phase, the production rate should be maintained at the predetermined EPR in order to make the most efficient use of the available industrial resources. If a change in production rate is required, it should be to one of the predetermined production rate levels. In any case, before deciding to deviate from the EPR, associated production cost increases should be considered.

The production cost changes resulting from a change in production rate may be estimated either through direct discussion with the manufacturer, or through a modelling technique, or both. There are several models that can be used to predict the effect of production rate change on unit cost. Unfortunately, many models require data that are very difficult to obtain, such as contractor variable and fixed costs.

Because Advanced Technology was not able to obtain the manufacturers' fixed and variable overhead costs, an aggregate of manufacturer's costs was used in this study. Where possible, fee and Government Furnished Equipment (GFE) costs, which do not vary with production rate, were removed from price figures to more closely approximate manufacturing cost.

The model most often used in support of this study is one that has also been used by Mr. John C. Bemis, formerly of the DoD Product Engineering Services Office (PESO). Through a multiple regression analysis of cost and schedule data, an equation was derived for each program studied. This equation associates the manufacturer's unit cost ("UC" in the equation below) with the cumulative number of units produced (Q), and the rate of production of the item (R). The equation is shown below:

$$UC = (k)\ Q^{-.xxx}\ R^{-.yyy}$$

If the logarithms of the variables are plotted, the surface described by the equation is a plane. A family of straight, parallel isocost lines* can be constructed on this plane with a slope that indicates the relative importance to unit cost of the cumulative quantity and production rate. This chart can be used to evaluate the cost efficiency of the production of the item.

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* All points on an isocost line have the same unit cost.

Although knowing the effect of a production rate change is important in the decision process, it does not, by itself, define the rate of production at which unit costs are minimized. No simple analytical model was found to define "economic production rate". The definition is based upon the results of discussions with members of the defense systems acquisition community. To describe this rate it was necessary to use the terms "economic procurement rate" and "economic production rate." Economic procurement rate describes the rate of acquisition of the complete system. It is defined as "the rate of procurement that permits efficient use of available industrial resources to achieve the lowest unit cost." The word "procurement" is used to distinguish between the acquisition rate of the system and the rates at which the components of the system are produced. In practice, each contractor has its own economic production rate. These rates must be taken into account when evaluating the procurement rate of the system. The contractor with the lowest economic production rate will act to limit the overall procurement of the system. The economic procurement rate, by definition, is the same as the lowest economic production rate of the contractors. It should be noted that this definition of EPR is not associated with the models which measure the cost effect of rate changes. The EPR is determined by the government program management office through discussion with the contractor(s). In this way the EPR for each contractor can be determined by evaluating the rate which will efficiently use the industrial resources available.

Five DoD acquisition programs have been examined in this study: the Army's TOW missile, Abrams M-1 tank, and Bradley Fighting Vehicle

System; the Navy's A-6E aircraft; and the Air Force's A-10 aircraft. For each program, a regression analysis yielded the equation previously described. For the A-10, sufficient information was available to also use a model suggested by C.H. Smith.

The economic procurement rate for each system studied has been determined and is presented in this report. The dollar savings have been estimated for producing at a more economical rate of production rather than at lower, actual or projected rates.

The economic production and procurement rates are goals; however, in practice, contractors usually produce and program offices usually procure below the optimum rates. The prevalent reason for procuring (producing) below the EPR is affordability. Other reasons are: to keep a "warm" production base, and lack of an identified requirement for a follow-on system.

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1. INTRODUCTION

1.1 Background

In his April 30, 1981 memorandum on "Improving the Acquisition Process,"[1] Deputy Secretary of Defense Frank C. Carlucci affirmed an acquisition management principle when he directed that:

> We must achieve more economic rates of production.

This principle became Recommendation Number 7:[2]

> Services must use economic production rates in their program and budget requests, or explain and be prepared to defend the reason why a different rate was selected.

Finally, in a July 23, 1982 memorandum entitled "FY 1983 Revised and FY 1984 Budget Estimates Guidance," the Deputy Assistant Secretary of Defense (Program/Budget), in his instructions for FY 1984 budget estimates, directed that:

> For major procurements contained in the aircraft, missile, ship, weapons, and tracked combat vehicles appropriation, a new exhibit in the format of Enclosure 3 will be required to indicate the most economical procurement rate of production and compared against the budget procurement rate when these rates differ.[3]

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[1]Frank C. Carlucci, Deputy Secretary of Defense, "Improving the Acquisition Process," 30 April 1981, Recommendation 7, "Economic Production Rates," p. 2.

[2]Ibid., p. 7.

[3]Clyde O. Glaister, Deputy Assistant Secretary of Defense (Program/Budget), "FY 1983 Revised and FY 1984 Budget Estimates Guidance," 23 July 1982, p. 3.

The enclosure referred to, requests the economic rate, budget rate and differences for FYs 1984-88 and explanations for the differences. According to the originating office, no significance should be attached to the substitution in that memorandum of the term "economic procurement rate" for "economic production rate."

1.2 Purpose

The objectives of this study as outlined by the Defense Systems Management College were:

o Determine, using sound microeconomic theory, how the theoretically optimum production rate is determined. This optimum rate is the rate which yields the minimum cost per unit cost of production.

o Determine the underlying reasons which may be related to cost, schedule, and political factors, why some programs are not produced at an economic rate.

o Rank the major factors causing "non economic" rates of production. (These factors are the program constraints in each program studied.)[4]

[4] Request for Proposal, MDA 903-82-G-0051, Task Order No. 82-4, Delivery Order 0002, 2 August 1982.

Although these objectives are clear, very early in the conduct of the study a reason was found to challenge the definition of optimum (economic) production rate given above. The basis for this challenge is that unit cost may not reach a minimum within practical limits. This led Advanced Technology to the development of a practical definition of economic production rate.

1.3 Scope

The research for this study was conducted with a desire to balance theory with practice. After conducting a literature search on the subject of the effects of production rate on unit cost, it was decided not to develop a new theoretical model. The best approach appeared to be to proceed immediately with the practical application of existing models to find the economic production rates. Dr. C.H. Smith stated in a review of the pertinent literature, "The studies clearly demonstrate that it is unrealistic to expect to obtain a general straightforward rate-cost model."[5] Therefore, emphasis was placed on finding (with the use of available data) a workable, empirical model that could be used, even if imperfectly, to relate unit cost to production rate.

These are several limitations to the scope of this study. First, the "per unit cost of production", which was referred to in the first

[5] Charles H. Smith, Production Rate and Weapon System Cost: Research Review, Case Studies, and Planning Model, APRO 80-5 (Fort Lee, Virginia: U.S. Army Procurement Research Office, (November, 1980)), p. 4.

study objective, is the cost to the producer, not the price to DoD. Because this information can be used to gain competitive advantage, it is considered proprietary by manufacturers and they would not release it for this study. The difference between the manufacturer's cost and DoD price is fee and government furnished equipment (GFE) costs. Where possible, fee and GFE costs have been excluded. Because fee and GFE costs do not have a predictable relationship with the rate of production, their presence must be considered contaminating. They detract from the correlation of the cost data with rate of production. A second limitation to the study concerns the number of manufacturers involved in producing components of the system. The cost of each part will vary with the production rate of that manufacturer, and, because there is a large number of manufacturers associated with any major system, it was beyond the scope of this study to evaluate all of them. On the other hand, the more customers a manufacturer has for a part or component, the less influence any one of these customers will have on the cost of the part. To take an extreme example, a DoD system is unlikely to have any affect on the cost (not price) of common fasteners regardless of what rate of procurement it sets, but may have a great affect on the cost of a component that is manufactured for that system only.

The cost of the final system may, therefore, vary significantly with only a few manufacturers. The number of contractors selected to be included in a study to determine EPR depends on the accuracy required. At the DoD level, where major changes in funding are made, accuracy does not have to be as precise as at the program office or at the prime contractor's level where more manufacturers should be included in the study in order to obtain greater accuracy. This study was generally limited to variations in

the prime contractor's cost only. Therefore, the study should be considered as a pilot study showing the methodology of analysis and the preliminary findings of the economic production rate of five DoD acquisition systems.

1.3.1 Selection of Systems for Study. Advanced Technology was directed to select five of the following nine major systems for detailed study:

Abrams M-1 Tank (Army)

Bradley Fighting Vehicle System (Army)

Patriot Missile (Army)

A-6E Aircraft (Navy)

P-3C Aircraft (Navy)

A-10 Aircraft (Air Force)

F-18 Aircraft (Navy)

KC-135 Aircraft Re-engining (Air Force)

TOW Missile (Army)

The following criteria (with explanations) were used to select the five systems.

- Include a system from each service. Because the conclusions of the study could influence all the services, it was decided that the three major services should participate. The best way to ensure each service's active participation, and to keep it informed of the progress of the study, was to include a program from each service. This criterion was also necessary to be able

to account for differences in management styles or administrative approaches among the services.

- Include programs with a variety of production rates, lengths of production runs, and sales. It was felt that the problems of a system with a high rate of production would differ from those of a system with a low rate.

  The length of time a system has been in production usually determines the amount of historical data available. A mix of systems with historical and predicted data was included. Programs with foreign military sales (FMS) were include because the FMS cause overall production rates and quantities to vary.

- Data must be available for study. Early in the study it was recognized that the portion of the unit cost that would vary with the production rate would be the manufacturer's unit cost; therefore, an attempt was made to select systems for which this data would be available.

- There must be a single prime contractor for the manufacture and assembly of a major portion of the system. It was recognized that cost variations resulting from changes in the rate of production would apply to the contractor doing the work. When the work is spread among many contractors, the effects of any one contractor's cost variation are not always significant in the overall cost of the system.

1.3.2 Systems Eliminated. Applying these criteria, the following systems were eliminated from the nine programs identified by DSMC. (This left five programs for review, as required by the contract.)

Patriot Missile: This system has several major components, each produced by a different contractor.

P-3C Aircraft: The available data were distorted and no hope was offered for better data. A Lockheed study on the subject was identified, but access to it was denied by Lockheed.

F-18 Aircraft: During the period of the study, this program was involved in a dispute between the Department of the Navy and the contractor over costs and the data that were available were minimal.

KC-135 Aircraft Re-engining: Production had not begun, and only projected data existed.

1.3.3 Systems Selected. The systems selected for study were:

Abrams M-1 Tank: a major Army system with some production history and a relatively high rate of production. It is produced in a Government-Owned-Contractor-Operated (GOCO) plant. This presented an opportunity to study the aspects unique to that contracting method. Prime contractor: General Dynamics.

Bradley Fighting Vehicle System: a system in production for only a short time, but with available data. Prime contractor: FMC.

A-6E Aircraft: a mature Naval aircraft with a low rate of production. Prime contractor: Grumman.

A-10 Aircraft: an Air Force aircraft with a long history of production. Prime contractor: Fairchild Republic Corporation.

TOW Missile: an Army system with a long history of production at a high rate. Prime contractor: Hughes Aircraft Company.

1.3.4 <u>Meeting of Interested Parties</u>. On 14 December 1982, a meeting on the subject of this study was held at the Defense Systems Management College (DSMC), Ft. Belvoir, VA. Participants included representatives from the Office of the Secretary of Defense; the program offices of the systems selected for study; Headquarters, Army Materiel Development and Readiness Command (DARCOM); Headquarters, Air Force Systems Command (AFSC); Headquarters, Naval Air Systems Command (NAVAIR), the DSMC; several defense contractors directly involved with the systems under study; and Advanced Technology, Inc. The first draft of this study was reviewed and discussed. The results of the meeting had a significant influence on the results of this study.

2. ECONOMIC PROCUREMENT/PRODUCTION RATE

2.1 Definition

Mr. John C. Bemis of the DoD Product Engineering Services Office (PESO) has found that for the majority of defense acquisition programs unit costs decrease as procurement rates increase.[6] The logical but impractical conclusion is that infinite rate gives minimal cost. Affordability considerations require that the rate of procurement must be limited to a realistic level. The industrial resources that determine the economic rate of procurement are: tooling and test equipment, plant space, manpower, and material. Because most defense systems are the product of a number of manufacturers, the term procurement is used in the definition to imply that the production rates of individual contractors result in a procurement rate for the system. The definition suggested by this study is:

> "The economic procurement rate of a system is the rate that permits efficient use of available industrial resources to achieve the lowest unit cost."

2.2 Explanatory Notes

The following notes apply to the above definition:

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[6] John C. Bemis, "Analysis of Rate/Cost/Quantity Relationships: Data Summary (Mar 81)," Department of Defense Product Engineering Services Office, Defense Logistics Agency, Cameron Station, Alexandria, Virginia. (Typewritten.)

1. When applying the definition to a single manufacturer, the term "economic production rate" may be used.

2. During production planning it may be possible to establish a procurement rate that will efficiently utilize all the available resources of the manufacturers, even if it means providing additional funds to some of them in order to meet the agreed upon schedule. If all manufacturers optimize their industrial resources to that rate, this rate will be the economic procurement rate and all manufacturers will have economic production rates to match it. In a more mature program, however, events often lead to a separation of rates as shown below:

EXAMPLE 1

higher rate
(planned)

Procurement or Production Level

Level A - Manufacturer A - economic production rate
(original economic procurement rate)

Level B - Manufacturer B - economic production rate

Level C - Actual procurement rate

lower rate
(actual)

In Example 1, the actual procurement rate, has fallen to Level C, far below the planned EPR at level A. The reason for the drop is not important to the example, but, typically, might be caused by a restriction of funds. Manufacturer A still has all the resources to produce at Level A and retains A as its economic production rate, although this now comes from a production

capacity in excess of the needs of the program. Manufacturer B has responded to the lower required rate by diverting some resources to another job. It now has a lower economic production rate at Level B. This rate is still higher than the rate required, but it is closer to the actual rate than Manufacturer A's rate. This means that Manufacturer B has less excess capacity than Manufacturer A and the government is paying a lower production rate penalty (proportionately) for Manufacturer B's product than for Manufacturer A's product. A pertinent question in this situation is, "What is the economic procurement rate of the system now?" Total industrial resources are not presently available to procure at a rate higher than Manufacturer B's rate (i.e., Manufacturer B's rate is limiting). Furthermore, because unit cost usually goes up with a decreasing procurement rate (as will be discussed in Section 3), it is uneconomical to procure at a rate less than Manufacturer B's rate. Manufacturer B's rate is therefore the present economic procurement rate and is the rate that corresponds to the lower economic production rate of the two major contractors.

3. The EPR may vary as the available industrial resources vary. This variation can be caused by the following:

   a. A government decision, such as a change in the specification of the item, a change in the level of facilitization support, and the closing or opening of a related production line. Note that changing only the actual rate of

procurement does not necessarily change the manufacturer's industrial resources. Therefore, a restriction of procurement funds, which results in a change in the rate of procurement, does not, by itself, change either the economic <u>production</u> rate of a manufacturer or the economic <u>procurement</u> rate of the system.

b. A contractor decision, such as changing a production process, opening or closing a related production line, changing vendors or subcontractors, or other decisions which would have an affect on the industrial resources available to support production of a defense system.

c. Actions beyond the control of either the government or the contractor, such as an act of God, a strike, or a restriction of a critical component by a sole source vendor.

4. At the contractor level, the economic <u>production</u> rate is determined by a single industrial resource which limits production or assembly of the component being produced. An industrial resource becomes limiting when its capacity is fully utilized while, at the same time, there is excess capacity in the other industrial resources. To be considered available for supporting the EPR, the resources must be at the location needed, and their costs must fall within approved fiscal constraints.

The following industrial resources become limited for the reasons presented:

a. Additional tooling and test equipment are available until the capacity is fully utilized, while still allowing time for maintenance.

b. Plant space is available until the capacity is fully and efficiently utilized.

c. Manpower is available until additional man-hours of the required levels of skill are not available, allowing for planned absences.

d. Materials are available until the supply of one of the following cannot be increased:

(1) raw material

(2) GFE/GFM (Government Furnished Equipment/Government Furnished Material)

(3) vendor or subcontractor supplied items

2.3 Discussion

Although the cost savings gained by procuring defense systems at the most economical rate may be substantial, they must be measured against other costs on a program. Procurement costs represent one component of life cycle cost. Operating and support (O&S) costs, a large component of

life cycle cost, will be affected by the rate of production. The decision-maker may be forced to choose between reducing immediate (small) production costs, or future (large) O&S costs. The definition of economic procurement rate suggested in this study does not apply to the aggregate life cycle costs, rather, it applies to the sum of the production costs. Furthermore, the definition does not consider all of the factors that may make the cost of the EPR unaffordable. Some of the other factors that affect costs are competing programs and budget cuts. These are reasons for not attaining the EPR, but they do not change the EPR.

There are other, non-economic factors that may favor producing a product at a rate other than the EPR. These factors include such things as keeping a warm production base, a change in the threat, technical improvement or failure and political considerations. These factors may dictate a specific rate of procurement, but they do not change the EPR.

The term "economic procurement rate" implies that there is a rate of procurement that is more economical than any other rate. Further, it implies that there is a relationship between unit cost and procurement rate, and that unit cost can be reduced by selecting a procurement rate close to the EPR. Also, because the rate of procurement is related to the rate of production of each manufacturer, the cost that should be studied is the manufacturer's cost of production, not the price of the product to the government. If the relationship of unit cost and the manufacturer's production rate can be established by both the government and the contractor, both parties can benefit by taking steps to reduce production costs.

The prime contractor is the focal point for system costs. The cost of production of a system consists of both the costs of components manufactured and assembled by the prime contractor and the costs of components that the prime contractor does not manufacture and assemble, but which he integrates into the system. Elements of GFE/GFM are furnished to the prime contractor at no cost to him and they will have separate EPRs. Vendors and subcontractors supplying items to the prime contractor will also have separate EPRs. It is easy to see, then, that the level of effort and amount of information needed to correctly model the cost of a major system will grow prohibitively large if all of the contractors, vendors, and subcontractors are considered. A compromise must be reached. While the definition of economic production rate is equally applicable to the manufacturer of any item in a system, in the weapons systems studied (except for the Fighting Vehicle System) Advanced Technology has used the costs and factors of production of only the prime contractor. Many of the vendor and subcontractor costs are included in the prime contractor's costs; therefore, they are not totally ignored. The contractors, whose costs were not included in the prime contractor's costs, were not analyzed independently.

During the Full-Scale Development Phase of a program, a procurement schedule (rate) should emerge that considers operational requirements, life cycle cost, affordability, and other factors pertinent at the time. Another production rate consideration should be the industrial resources the potential contractors will devote to the system throughout the production period. Inflexible excess would result in uneconomical production rates. The production rate might be made a negotiable factor for contractors. Cost could be used as a trade-off. When a schedule is agreed upon,

it becomes the basis for the contractor to optimize the levels of the industrial resources that will be applied to the production of that system. That is, production processes will be selected that are best suited to that rate. Quantity of production, plant space, tooling and test equipment, manpower and materials (in the form of raw material, and subcontractor and vendor items) will be optimized to reduce unit cost. To the extent that this is accomplished, the EPR and the planned production rate will be the same. Later, however, circumstances may occur that will affect the actual schedule, as well as the EPR. For example, if all else remained equal, but the government decided to stretch-out production, the EPR would remain the same because the industrial resources would not changed. However, the actual procurement rate would decrease. There would be a unit cost increase (measured in constant dollars), which, when multiplied by the total number of units produced, would be a penalty for procuring at a rate lower than the EPR. (During periods of inflation there would be an even larger current dollar penalty.) If a contractor were able to reduce one or more of the resources that affect the EPR, such as giving up plant space to another job, the EPR would be lowered, thus bringing it closer to the actual procurement rate. The cost penalty of procuring at a rate lower than the EPR would be less. The following examples may help clarify these points.

EXAMPLE 2

New Program

Procurement or Production Rate	Full Scale Development Phase	Production Phase
↑	Level A Original EPR (all contractors facilitize to this rate)	A Planned +1
	Level B Preplanned -1	B Actual rate (New EPR)
	Level C Preplanned -2	C Planned -1

In Example 2, Level A was the planned rate of procurement to which all contractors facilitized. Two lower preplanned rates B and C were negotiated in case the procurement rate fell at a later time. During production, events (budget constraints, shortages of critical items, etc.) may cause the actual procurement rate to fall to Level B. All contractors would shift to Level B, and Level A would remain a higher (+1) option and Level C would remain a lower (-1) option. Ideally, the contractors would use the excess capacity for other products, or they would reduce their resources by other means. Then, Level B would become the new EPR. If not, the situation may be as shown in Example 3.

EXAMPLE 3

Mature Program

Procurement or Production Rate

Early Production Phase		Later Production Phase	
Level A	Original EPR	A	Original EPR
Level B	Prime	B	+ 2
Level C	Sub (present EPR)	C	+ 1
		C1	Actual procurement and compromise EPR
Level D	Actual procurement	D	- 1

Early in the production phase of this program, the actual procurement rate dropped from the original EPR at Level A to a lower procurement rate (Level D). The prime contractor and subcontractor both reduced their resources, but they did not reduce them to Level D. The prime contractor's economic production rate is at Level B, and the subcontractor's economic production rate is at level C, which, by definition, is also the economic procurement rate on this program. Unit cost could be reduced, either by

raising the level of actual procurement or by reducing resources and lowering the contractor economic production rate. In this example, Level C1 was agreed upon as the target EPR. All of the contractors reduced their resources to optimize their production at that level, and the actual procurement rate was raised to that level. Levels B (+2), C (+1), and D (-1) remain as options. This, of course, represents an idealistic solution. A complete solution will probably never be as easy to realize in practice. Regardless, the problem of uneconomical production rates can be reduced by these methods.

The economic procurement rate has a baseline unit cost against which unit costs of various rates may be measured. The financial penalty of not producing at the EPR can then be estimated. If the EPR cannot be lowered by the contractor, there may be valid reasons for still procuring the system, even at a rate below the EPR. Operational requirements, technical problems, affordability, keeping a "warm" production base and a number of other excellent, and often over-riding, reasons may require production at a level below the EPR. However, the cost of not producing at the EPR should be measured and considered during the decision-making process.

Although the study report uses the single term, EPR, it is recognized that the vast complexities that surround this subject make pinpoint accuracy impossible. Because industrial resources often come in discrete blocks, there may be a "break point" near the theoretical EPR which will be the practical EPR. It may become obvious only through a discussion with the contractor. This, however, does not negate the importance of (a) an independent government estimate of the EPR, or (b) reporting the cost penalty caused by deviation from the EPR.

3. MODELS

In finding the EPR for a system or contractor, the definition is of paramount importance. At the theoretical EPR, there are no wasted industrial resources. At the practical EPR, the excess industrial resources are minimized. The government can influence the level of resources during early planning. However, the government can only discover the actual EPR through discussions with the contractor. Of equal importance to establishing the EPR is the capability to estimate the change in unit cost which results from a shift in the rate of procurement or production. First, this capability can be used to measure the cost penalty of not producing at the EPR. Even if the EPR cannot be attained. it can act as a baseline from which cost deviations can be measured. Second, this capability will allow planners to estimate the impact that production rate shifts have on unit cost. Third, this capability will permit planners to estimate the unit cost penalty if the production rate is reduced. This capability is achieved through modeling.

Classical microeconomics predicts the existence of a minimum unit cost as production rate increases (holding industrial resources constant). However, for defense systems, this unit cost is not normally attained during peacetime. Under-utilization of available capacity is one of the problems that must be addressed. Raising the rate of production usually results in a lower unit cost, if the capacity of the facility is not exceeded. An inverse exponential relationship between unit cost and production rate appears to exist.

The models described below were found in the literature. They attempt to describe the relationship just discussed.

3.1 "Knee of the Curve"

During this study a model was sought that would both help to define EPR and provide a method for measuring the cost incurred by not following the EPR. One of the first models found was the "knee of the curve."[7] This model assumes only an exponential relationship between production rate and unit cost. The specific relationship for an item could be found empirically by historical production data, contractor proposal data, or prior experience with the contractor producing similar items. The graph would be shown as:

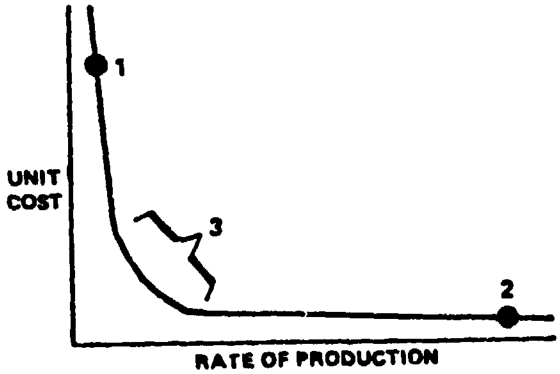

FIGURE 1

The model assumes that if a program's plot of present production rate versus present unit cost is on the vertical leg of the curve, such as point number 1 in Figure 1, the rate would be too low and the unit cost too high. It follows, then, that a relatively small increase in rate would yield a

[7]William A. Long, Deputy Under Secretary of Defense (Acquisition Management), "Acquisition Improvement Task Force," (Washington, D.C.: Department of Defense, (23 December 1981)), p. 7-2.

large reduction in unit cost and the production rate could be raised for a small cost. If a program's position is on the horizontal leg of the curve, as at point number 2, the program would be in a region in which only a relatively small reduction in unit cost is achieved through a relatively large change in production rate. (Here, cost could be recovered by a relatively small reduction in rate). The ideal position (or EPR) on the plot would be near the "knee" of the curve at point number 3. This is where a large cost reduction for a relatively small increase in rate comes to an end. The EPR, then, is defined by the "knee" of the curve.

The usefulness of this model is dependent on the scales selected for the axes. By changing the scales as shown in Figure 2, the plotted point

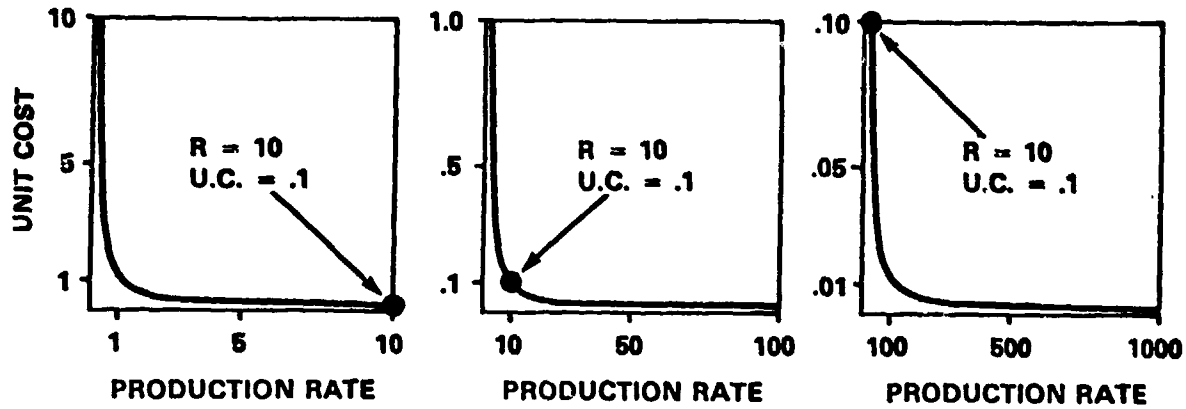

FIGURE 2

moves from the horizontal arm, to the knee, to the vertical arm without a change in either unit cost or rate of production of the program. In all these cases the curve is the plot of the relationship: unit cost (U.C.) is equal to the inverse of the production rate. This model might be valuable if a single, meaningful scale could be found for a particular program or a set of programs. It must be used with caution, and it was not used in this study.

To avoid these pitfalls of the model just described, it is better to plot an exponential curve using log-log graph paper. Then the curve appears as a straight line (Figure 3) and the "knee" disappears. This graphically demonstrates the difficulty of using the "knee of the curve" to derive a general definition for EPR.

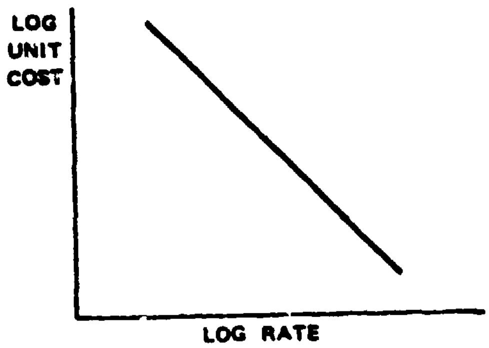

FIGURE 3

3.2 Balut Model

The model described by Commander Steve J. Balut[8] is one used in the Program Analysis and Evaluation (PA&E) Directorate in the Office of the Secretary of Defense. It is shown below:

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[8]Steve J. Balut, Commander, USN, "Redistributing Fixed Overhead Costs," Concepts 4, No. 2 (Spring 1981): 63.

$$F_i = \left(\frac{Q_i^{\text{old}}}{Q_i^{\text{new}}}\right)^b PR + (1-PR)$$

where:

i = lot number

F_i = adjustment factor for rate applied to standard learning curve estimate

Q_i^{old} = old quantity

Q_i^{new} = new quantity

P = the fraction of price represented by overhead

R = the fraction of overhead that is fixed in the short term

b = exponent to improve model, i.e. experience factor.

This model relates the rate factor to fixed overhead. Balut used data from the Acquisition Management Contractor Cost Data Reporting (CCDR) System. This consists of three reports: the DD Form 1921-1, "Functional Cost-Hour Report"; DD Form 1921-2, "Progress Curve Report"; and DD Form 1921-3, "Plant-Wide Data Report." These reports are described in a single pamphlet[9] with the following descriptive numbers:

Naval Material Command Pamphlet	NAVMAT	P-5241
Army Materiel Command Pamphlet	AMCP	715-8
Air Force Logistics Command Pamphlet	AFLCP	800-15
Air Force Systems Command Pamphlet	AFSCP	800-15

These reports pass through the Services and are kept at PA&E. Unfortunately, access to these reports for this research effort was

[9] Department of Defense, Acquisition Management Contractor Cost Data Reporting (CCDR) System NAVMAT P-5241, AMCP 715-8, AFLCP 800-15, AFSCP 800-15, 15 November 1973.

denied; therefore, with one exception, the study team was unable to obtain fixed costs or overhead for the programs studied. An exception was the A-10 program, for which similar data was obtained from a predecessor report to the CCDR (the DD Form 1558, "Contractor Information Report," that is still being used with the A-10).

3.3 C.H. Smith Model

Dr. C.H. Smith prepared an excellent summary of applicable research in November, 1980.[10] It provides suggestions for a practical approach to the problem of incorporating rate into cost estimates. He proposes that during early planning, rate effects on unit cost be ignored. However, during budgeting, estimators should use either one of the predictive models he describes, or a rule of thumb that unit cost will increase 0-10% per 50% rate reduction. During contract negotiations, he recommends use of (1) a predictive model, (2) a rule of thumb, or (3) a regression model such as described by L.L. Smith below. The predictive model he recommends is based "largely on the premise that fixed overhead is the primary explainer of cost-rate effects." The model is:

$$A = \frac{\sum_{k=1}^{Q} ak^{-b} + T_1 F}{Q}$$

which can be approximated by

$$A = \frac{\frac{a}{1-b} Q^{1-b} + T_1 F}{Q}$$

[10]Charles H. Smith, Production Rate, p. 4.

where:

A	=	average unit cost for all production
Q	=	total quantity of units to be produced
T_i	=	acquisition period in years
F	=	annual fixed costs
b	=	exponent in variable unit cost learning curve equation $y = ax^b$
a	=	first unit cost

This model combines a cumulative quantity factor based on variable costs and a rate factor based on fixed costs. Unfortunately, it is not easy to predict fixed and variable costs.

3.4 L.L. Smith Model

LTC L.L. Smith used regression analysis to fit data from airframe production periods using the following model:[11]

$$Y_i = B_o \cdot x_{1i}^{B_1} \cdot X_{2i}^{B_2}$$

where:

Y_i	=	the unit average direct labor hours required per pound of airframe in lot i
x_{1i}	=	measure of cumulative production that is one-half the i^{th} lot size plus the total production of all prior lots
x_{2i}	=	the lot i production rate

B_0, B_1 and B_2 are the model parameters to be determined by a least-squares fit.

[11] Larry L. Smith, "An Investigation of Changes in Direct Labor Requirements Resulting from Changes in Airframe Production Rate," (Ph.D. dissertation, University of Oregon, 1976), quoted in Charles H. Smith, Production Rate, p. 11.

Smith found some data correlation in programs with long production histories. He concluded, however, that the model is valid only within a single program and is not transferable.

3.5 J.C. Bemis Model

J.C. Bemis took the L.L. Smith model and substituted unit cost for Y_i and applied it to many DoD acquisition programs. His model[12] takes the form:

$$UC = (k)\ Q^{-.xxx}\ R^{-.yyy}$$

where:

UC is the unit "fly away" cost of the Q^{th} item produced at rate R. Constants k, .xxx and .yyy are determined by regression analysis using a least squares fit through the data points.

A physical model would appear as shown in Figure 4:

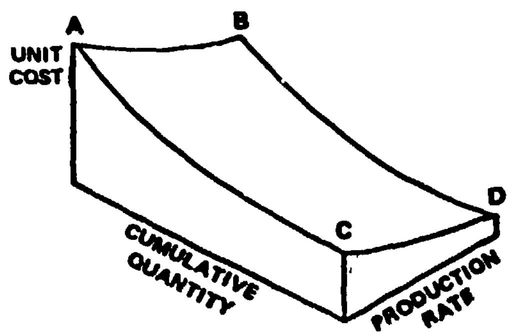

FIGURE 4

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[12] John C. Bemis, "A Model for Examining the Cost Implications of Production Rate," Concepts 4, No. 2 (Spring 1981): p. 85.

The scalloped surface A B C D represents the solution to the equation. Point A is the highest point on the surface and corresponds to cost of the first unit produced at the lowest production rate. It is also called the "prime unit cost." Note that curve AC is a cost improvement curve at the lowest production rate and point A corresponds to the first unit cost of that curve. The surface is concave with point D the lowest unit cost.

Another feature of the model takes advantage of the fact that unit cost can be lowered by increasing either cumulative quantity or production rate or both. Plotting combinations of cumulative quantity and production rate which yield the same unit cost will describe an isocost line. In other words, all points on an isocost line will have the same unit cost. A family of isocost lines is shown in Figure 5 below.

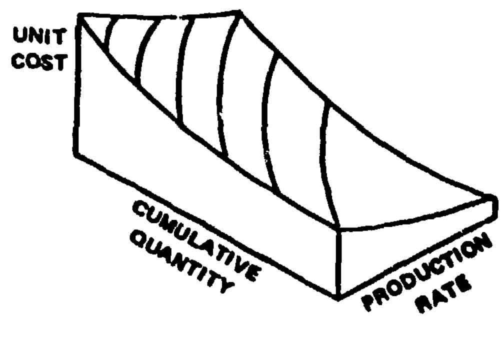


FIGURE 5

3.6 The "Rolling Ball" Extension to the Bemis Model

If the Bemis model is plotted using log values, a plane as shown in Figure 6, rather than a concave surface, will result.

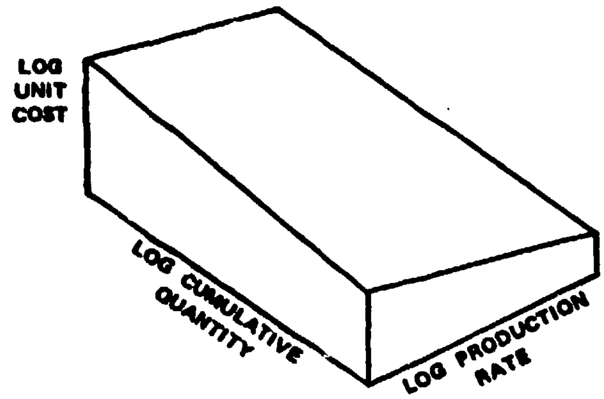


FIGURE 6

If a ball were placed at point A, as in Figure 7, and were allowed to roll down the surface, it would follow the straight line path AB.

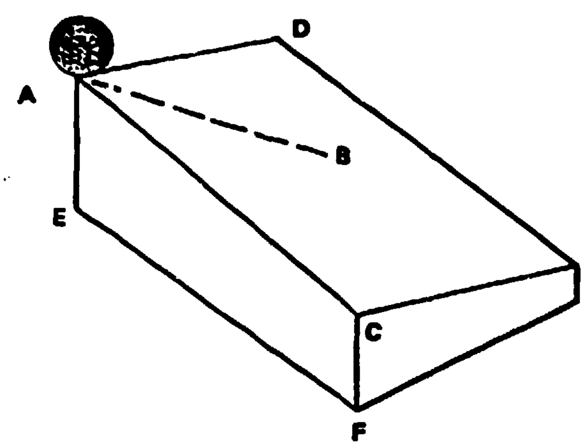


FIGURE 7

The path would be determined by the slope of the improvement curve AC and the the slope of the rate curve AD. Path AB could be described as the resultant AB of two forces AC and AD as shown in Figure 8:

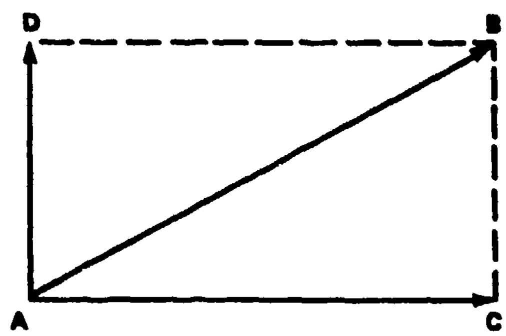


FIGURE 8

Since only the direction of the force AB is important and not the magnitude, only the relative magnitudes of forces AC and AD are needed. To find the relative magnitude of force AC, consider the face ACFE of the three-dimensional model in Figure 7 above. As shown in Figure 9, a constant force of gravity will be acting along AE. This force has a component AC parallel to the surface and a component CE perpendicular to the surface.

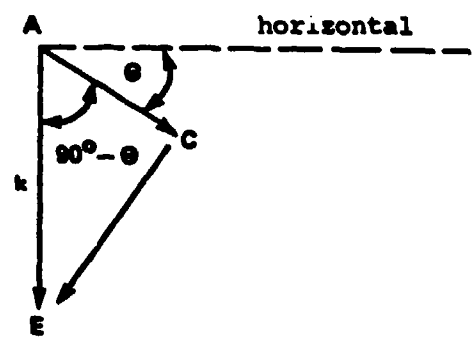


FIGURE 9

$$AC = k \cos (90^{\circ} - \theta)$$

$$AC = k \sin \theta$$

$$AC \propto \sin \theta$$

$$AC \propto \tan \theta \text{ (for small angles)}$$

θ is the angle that the log cumulative quantity curve makes with the horizontal. The tangent (slope) of θ is the exponent .xxx in the improvement curve equation:

$$\text{unit cost} = (k)\, Q^{-.xxx}$$

(k = first unit cost on the improvement curve)

So the force along AC is directly proportional to .xxx. Likewise, for small angles, the force along AD (Figure 7) is directly proportional to the exponent .yyy of a rate curve in an equation:

$$\text{unit cost} = (k')\, R^{-.yyy}$$

(k' = first unit cost on the rate curve)

Therefore, to find the direction of force AB, the path of the ball in Figure 8, the following force diagram may be plotted:

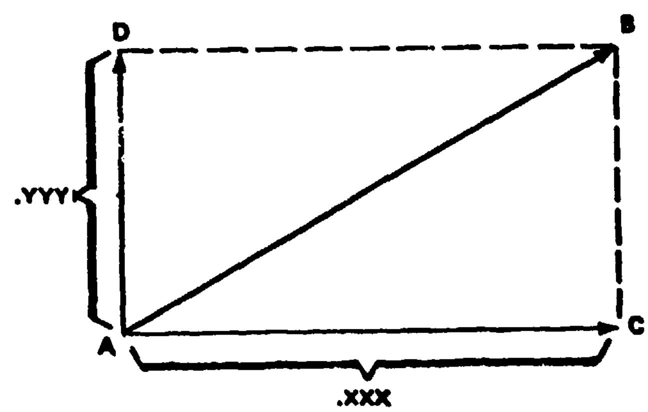


FIGURE 10

To plot this on log-log paper, the printed graph lines are ignored and a linear scale is used to plot .xxx and .yyy. As long as the same scale is used to plot .yyy and .xxx, the absolute scale selected is immaterial.

To see the characteristics of path AB, let us look again at the three-dimensional model plotted on log-log scales and with isocost lines added:

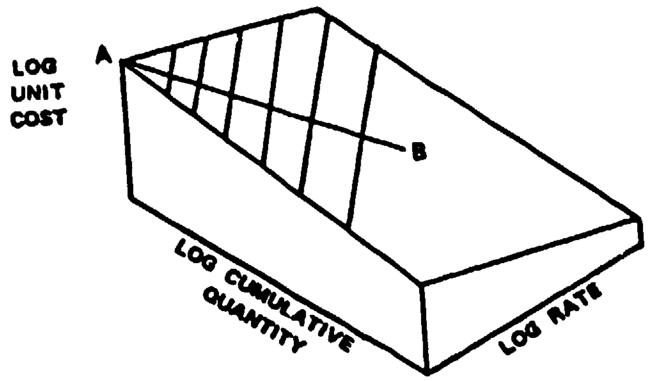
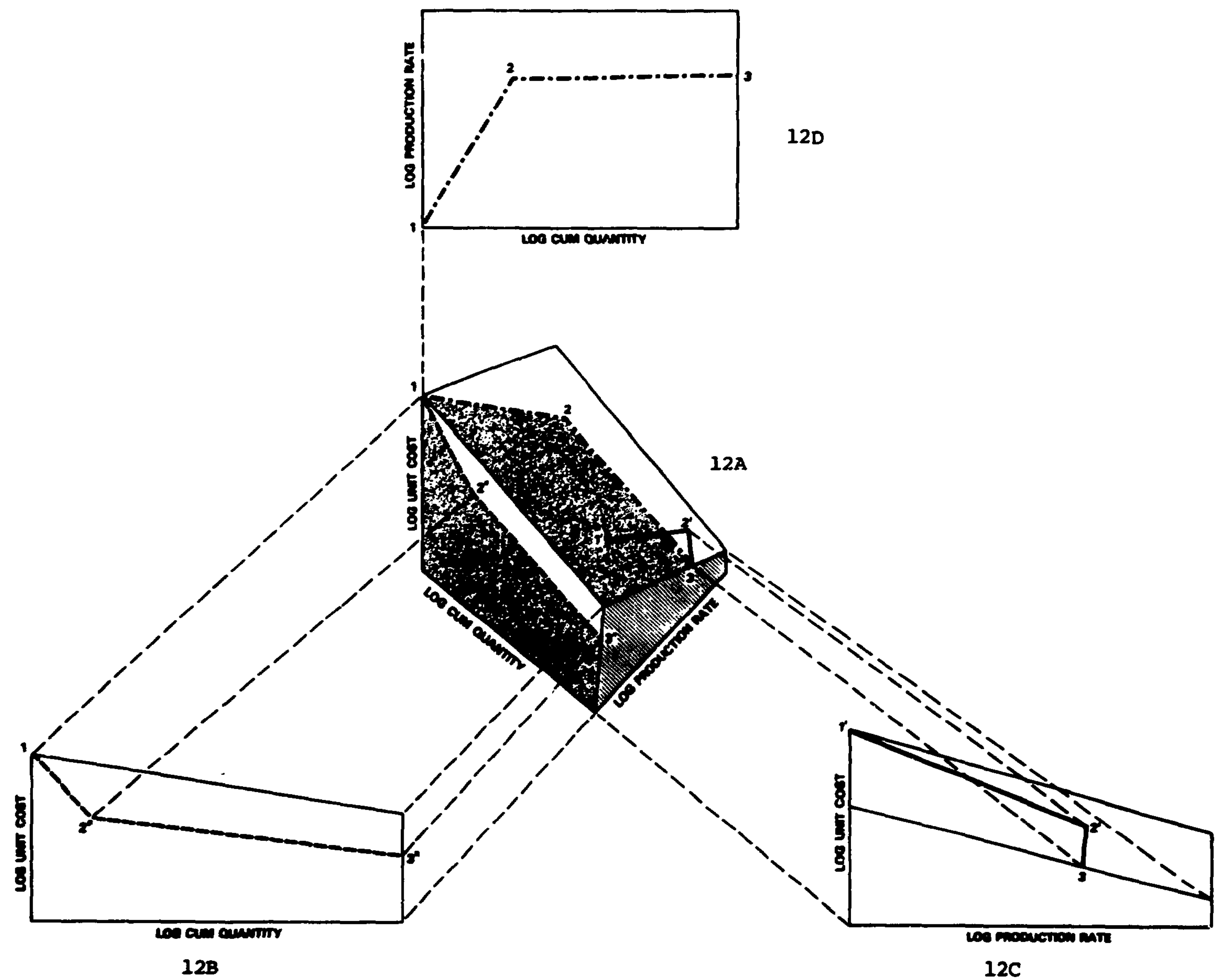


FIGURE 11

This time the isocost lines are straight and the path AB is perpendicular to them. This is logical, since, if the isocost lines are thought of as contour lines, a ball rolling down the surface will follow the steepest path, or one perpendicular to the contour lines.

This may be thought of as a possible practical path to follow during the build up stage of production. It is not the most economical, which would be one which started at the highest possible rate, produced at that rate until the required quantity was reached and then stopped. For major DoD systems, this is not practical and a planned build up to an EPR is required. However, once the Economic Production Rate (EPR) has been reached, it should be maintained until the end. The theoretical path in three dimensions with its projections is as shown on the next page.



LOG PRODUCTION RATE
LOG CUM QUANTITY
12D
LOG UNIT COST
LOG CUM QUANTITY
LOG PRODUCTION RATE
12A
LOG UNIT COST
LOG CUM QUANTITY
12B
LOG UNIT COST
LOG PRODUCTION RATE
12C

Figure 12

Figure 12B showing a "bent" improvement curve is similar to one described by Cox and Gansler[13] as resulting from producing while increasing the production rate. It is the projection of the top view (12D), however, that is most interesting. The slope of the isocost lines indicates the relative weight of cumulative quantity to rate. For example, the following three diagrams in Figure 13 show patterns of isocost lines.

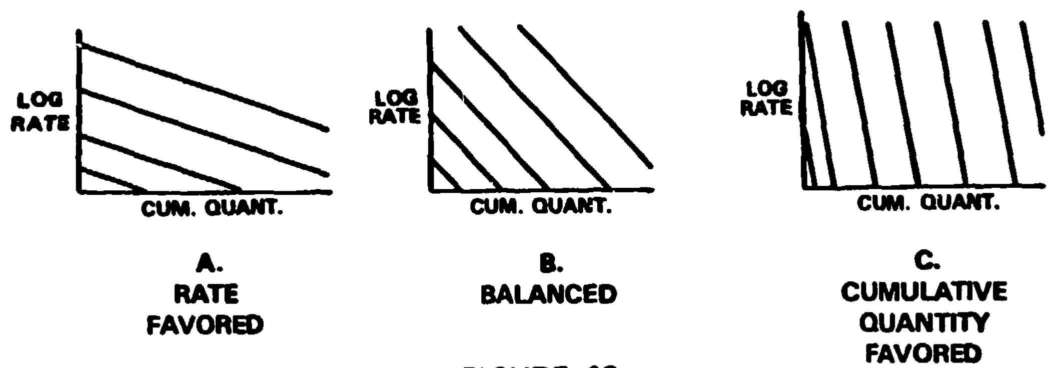


FIGURE 13

In each, the isocost lines furthest from the origin represent lower unit costs than those closest to the origin. The objective, then, is to move as quickly as possible from the starting point (a point on the Y axis) to the lowest unit isocost line before most of the production occurs. Figure 13A, "Rate Favored", depicts a situation in which the slope of the rate curve is greater than the slope of the improvement curve. A program with this type of graph is less adapted to long-term, low-level production than the other two cases. A low isocost line can be reached by rapidly increasing the producton rate. This high rate should be maintained until the required quantity has been produced. On the other hand, a program with a graph such

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[13] Larry W. Cox and Jacques S. Gansler, "Evaluating the Impact of Quantity, Rate, and Competition for Production of Weapon Systems," (Arlington, Virginia: The Analytical Sciences Corporation (15 May 1981)), pp. 4-3, 4-4, 4-5.

as 13C "Cumulative Quantity Favored", is more adaptable to low-level production than a "rate favored" program. This is evident if one observes that isocost lines are cut more readily by emphasizing cumulative quantity, rather than by increasing production rate even though both actions will reduce unit cost.

Figure 14 illustrates that the path perpendicular to the isocost lines is the shortest path between them. Since AC is shorter than either

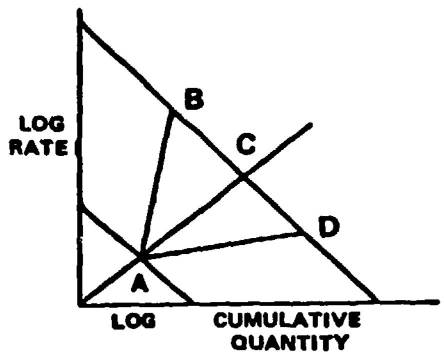

FIGURE 14

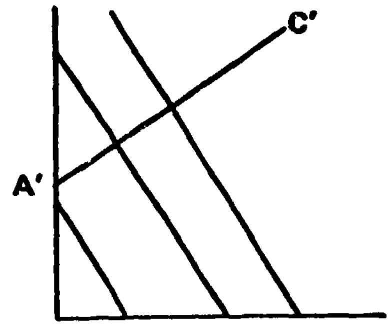

FIGURE 15

AB or AD, it is an "efficient" path to follow. Note also that it is the slope of AC that is important. If production had started at a higher level A' (Figure 15), A'C' would be the perpendicular to the isocost lines at the starting point A' and would have the same slope as AC.

4. CONSTRAINTS AND LIMITATIONS

A major constraint in this study was the lack of accurate data. Manufacturers' production costs were sought, but such information is proprietary and closely held by the companies. The cost data used were the best available, but did contain known and unknown inaccuracies.

The Bemis model[14] has not been independently validated by a thorough study. His model is an extension of the L.L. Smith equation[15] that used direct labor hours per pound of airframe as the dependent variable. The Bemis model as it is being used today, uses "flyaway" unit cost that includes government furnished equipment (GFE) and fee. To the extent that these costs are not related to procurement rate, error has been introduced. The high correlation factors, found over two years of working with the model, do suggest a relationship between unit flyaway cost and production rate, but correlations such as these could be caused by multi-colinearity resulting from an interdependence between the independent variables of cumulative quantity and production rate.

All costs of an item are not included in the analysis of the programs studied. Separate analyses of Government Furnished equipment/ government furnished material (GFE/GFM) should also be performed, just as has been done for the prime contractor. Also, vendors and subcontractors should be studied separately. The effect of rate on cost will finally be

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[14] John C. Bemis, "A Model for Examining," p. 84.

[15] Larry L. Smith, "An Investigation of Changes in Direct Labor Requirements," quoted in Bemis, "A Model for Examining," p. 85.

lost when the demand of a single program does not significantly change the production rate of the manufacturer. Thus, the costs of third and fourth tier vendors are not significant unless they create choke points.

The accuracy required is a function of the level at which the analysis will be used to make decisions. DoD will likely round off the figures at a much higher level than will the government program office, which, in turn, will not need figures as accurate as those required by the prime contractor.

Unit cost predictions using the Bemis model decrease in accuracy when the rate and quantity are extrapolated beyond the input data. In this study the most tenuous prediction is for the M-1 tank program in which cost was predicted for a rate twice that of the input data. This extreme extrapolation is supported somewhat in this case because the existing facilities and processes were chosen with the higher rate as a goal.

Finally, most changes in manufacturers' facilities and the configuration changes of the items were ignored in this study. Large, known deviations such as the production breaks in the A-6E program were noted, but smaller changes were not. This lack of detail requires that the results of the analyses of the five programs be interpreted only on a macro scale.

5.DATA

Early in this study it was discovered that the collection of detailed data would be a problem. The most readily available data were from the Five Year Defense Plan and Program Objectives Memorandum. However, these were predictions. They do not convey the many problems that arise during actual production. These data contained fee and other costs not subject to rate changes. Therefore, a concerted attempt was made to obtain data that reflected the prime contractors' costs.

The data used were obtained from government sources in the Office of the Deputy Chief of Staff, Research, Development and Acquisition (Army), the program offices, NAVAIR Cost Analysis Division, Hqs. Air Force Systems Command, and the Aeronautical Systems Division cost library at Wright-Patterson AFB. During visits to these locations, the definition of EPR was refined.

6. CALCULATIONS

Except for the three-month FY 76T period, which was handled on an individual program basis, each fiscal year raw datum point used in the regression analysis was identified by the logarithm of three coordinates, which were found as follows:

rate of production	=	quantity of items produced in the FY
unit cost	=	manufacturer's total FY cost ÷ total number of items produced in the FY
cumulative quantity	=	the arithmetic midpoint of the quantity produced plus the total quantity produced before that FY (The arithmetic midpoint was used for ease of calculation. The algebraic midpoint would be more accurate.)

Each of these three values was converted to its logarithm and the point thus identified was used as input to the analysis. The computer program found the best fit line through the points and provided the exponents and logarithm of the constant in the equation which was described previously:

$$UC = (k)\ Q^{-.xxx}\ R^{-.yyy}$$

Although many calculations, including linear regression analysis, were made using hand-held calculators, the multiple regression analyses and linear regression analyses conducted for record were done on the Boeing Computer Services Co. program "STATPK."[16] Summation calculations that integrated cost over years were also done on the "POM-84" program made available through the DoD Product Engineering Services Office (PESO).[17]

[16] Boeing Computer Services Company, "Mainstream-CTS: Interactive Statistics Package (STATPK)," Manual No. 10201-019-R1, March 1978.

[17] Department of Defense Product Engineering Services Office, Defense Logistics Agency, "POM-84" computer program.

7. CONCLUSIONS

- A clear, concise, acceptable definition of EPR was not found among the theoretical models studied. Therefore, it was necessary to establish a definition through compromise. The definition established covers most situations, is quantifiable, and gives practical results.

- Historic data and a mixture of historic and predicted data showed excellent multiple correlations between log rate, log cumulative quantity, and log unit cost.

- When Foreign Military Sales are anticipated, the FMS must be taken into account in determining the EPR. Commercial sales, if any, should also be considered.

- On a graph displaying the log production rate versus the log cumulative quantity, the slope of the isocost lines derived from a regression analysis indicates the relative importance of the production rate and cumulative quantity to an item's production unit cost.

- For the programs studied, the most common reason given for not being able to produce at the EPR was <u>affordability</u>. This was caused in part by the low priority of the defense systems (e.g., A-10) and a higher inflation than anticipated (e.g., FVS, M-1). In the case of the M-1, the cost of facilitization, rather than

the number of production items, affected the EPR. Another reason for not producing at the EPR was to keep the production base warm until a replacement system had been designated (e.g., A-6E). Still another reason for a low rate of production was that there was not an identified requirement for a follow-on system (e.g., TOW).

8. RECOMMENDATIONS

8.1 Recommendations for Action

8.1.1 The definitions of economic production rate and economic procurement rate be accepted and disseminated widely throughout the defense acquisition community. EPR must be defined before the associated (baseline) unit cost can be established.

8.1.2 In conjunction with the budget cycle, program offices should report the following information to their higher headquarters for evaluation and possible action to reduce unit cost:

a. Present and projected levels of procurement with associated unit costs.

b. Economic production rates of prime and major subcontractors.

c. The economic procurement rate for the system and the associated unit cost.

d. Contingency levels (with unit costs) higher and lower than the economic procurement rate that will effectively use available or planned industrial resources.

e. Ways and means to reduce the average unit cost of the system by lowering the economic production rates of

the contractors or raising the planned procurement rates of the system.

8.1.3 Production contracts should be written to anticipate changes in production rates and the quantity of the items to be produced. As Dr. C.H. Smith has suggested, "The government should require contractors to explain, as part of their proposals, the mechanism for accommodating rate changes." Another approach would be to ask for a contractor committment to costs at several rates. These preplanned rate levels would be similar to the -1 and -2 levels of Example 3 in paragraph 2.3. The data that will be needed by the government to independently estimate the effect of a rate change on unit cost should be included in the contract.

8.1.4 Defense systems production data should be systematically collected for analysis of the possibility of cost savings and for validation and refinement of cost models. Presently such data is sparse and decentralized. Two arguments for maintaining the detailed data at the service level or below are: (1) the data are often contractor sensitive, and, (2) except for aircraft, there are only limited similarities of systems between services. General figures on production schedules and prices could be usefully centralized at the DoD level, perhaps by the Defense Logistics Agency (DLA).

8.2 Recommendations for Further Study

8.2.1 Further verify the Bemis model by a detailed study of historic data from DoD programs. Estimated unit cost changes from production rate changes should be compared with actual unit cost changes. This or a similar model is needed in order to quantify unit cost variations corresponding to production rate changes. The Bemis model is attractive because it uses data reasonably available to the government, is simple to use, and is very flexible. However, the following two limitations of the model should be specifically studied:

a. To the extent that cumulative quantity and production rate are dependent on each other, the regression analysis of the Bemis model will be adversely affected. A direct correlation between the two exists during the build-up phase of production, but such a relationship is not obvious during long production runs. This relationship should be studied to determine its effect on the validity of the Bemis model.

b. The implications of a positive rate exponent or cumulative quantity exponent should be studied. Either of these would indicate "dislearning" and an increasing unit cost with increasing rate or cumulative quantity.

Both effects are possible, but actual cases should be studied closely to identify the causes.

8.2.2 Study the problem of smoothly phasing out one program while phasing in another program at a manufacturing plant. A related study could be conducted on the overlapping effects of multiple systems sharing the same manufacturing facilities.

8.2.3 Study the optimization of a spectrum of programs, rather than the optimization of only a single program. Programs in which rate changes have the greatest effects can be identified by the slopes of the isocost lines. This information can be used to indicate, from an economic point of view, which programs would be substantially affected and which would be only mildly affected if their procurement rates were changed. Other solutions to the excess production cost problem may become evident, but the question of which programs can accommodate a change to the production rate with minimal effect on the unit cost is important if overall defense spending is to be made more efficient.

8.2.4 Develop a multivariate model that will incorporate both economic and non-economic factors. EPR is only one of the many economic factors that influence the rate and quantity of defense systems acquisition. The results of EPR analysis should be weighed against the effects of

competition, the type of contract, and a multitude of other economic considerations. At the same time, the effects of non-economic factors, such as political and user requirements, should be evaluated. Finally, both economic and non-economic considerations should be reconciled to establish the best production rate and quantity schedule under the circumstances. Such a model would be very useful, not only in arriving at a final decision but, also, in systematically exploring the effects of all the combinations of factors in the fluid environment of systems acquisition.

8.2.4 Thoroughly study a very simple acquisition program that has good documentation. This study could determine the usefulness of the definition of EPR proposed in this study. Although it is evident that money can be saved by reducing manufacturing unit cost, the analysis must be kept as simple a possible in order to avoid placing an excessive burden on the program office. As with other new requirements, the benefit must be shown to far outweigh the cost. In order to determine the proper level of emphasis to be placed on EPR, the following questions raised by this study should be answered:

a. What is the accuracy of the Bemis, C.H. Smith, L.L. Smith and Balut models?

b. What is the effect on manufacturing unit cost of changes to the rate of production at both the prime contractor and the subcontractor levels?

c. How practical is it to reduce or redeploy industrial resources to meet lower production schedules?

d. Is there an accurate model that can accept flyaway cost or unit price as input?

8.2.6 The Defense Acquisition Research Element (DARE) should sponsor a meeting of those persons who have contributed to the basic theory of EPR. The purpose of the meeting would be to find a bridge between EPR models that are theoretically accurate, but often impractical, and those that are practical, but theoretically weak.

ABRAMS M-1 TANK ANNEX

A-1. General Background and Data Sources

The Abrams M-1 tank is produced by General Dynamics at two locations - Warren, Michigan, and Lima, Ohio. Although final assembly takes place in both plants, each plant produces some components used by the other plant. The government program office is located in Warren and reports to the U.S. Army Materiel Development and Readiness Command (DARCOM).

Manufacturing and final assembly at both locations take place in government-owned contractor-operated (GOCO) plants. The government owns the buildings and machinery. Neither manpower nor material is a limiting factor; therefore, facilitization determines the economic production rate. The term "facilitization" is used to refer to plant space, machinery, tooling and test equipment. Responsibility for the level of facilitization is shared between General Dynamics and the government. General Dynamics recommends processes and equipment and is responsible for implementing the production plan. The government provides the funding. Another unique aspect of a GOCO plant in this study is that, since the government owns the plant and machinery, charges for fixed overhead do not stop when production ceases; instead, they revert from the program to the service. For this reason, decision-makers should keep in mind that an economical production rate for the program may not be economical for the government because there is an idle plant and shut-down machinery after the end of production.

Data on the M-1 came from government program office figures supplied by the Office of the Deputy Chief of Staff Research, Development and Acquisition. Only General Dynamics manufacturing costs were used. Cost of government furnished equipment (GFE) was omitted. There are two known sources of error in the data. First, in FY 79, 80, and 81 some unknown cost for the vehicle, engine, transmission, fire control systems, and gun mount (all of which were later incorporated as GFE) were included in the manufacturing cost. Second, advanced procurement cost was omitted because only a partial set of data was available. Cost data used in the regression analysis to derive the rate-cumulative quantity-unit cost equation are dated 27 May 1982.

A-2. Production Rate

Economic Production Rate. General Babers, then Program Manager, in the FY 81 House Armed Services Committee hearings expressed concern about the ability of the second and third tier vendors to supply components at the levels needed for expanded production.[18] In spite of this concern, the immediate production limitation is tooling and test equipment.

Four monthly rates of production have been proposed: 60, on a 1-8-5 schedule; 90, on a 2-8-5 schedule; 120, on a 2-8-5 schedule; and 150, on a 3-8-5 schedule. The latter rate, 150/month, is considered to be a surge

[18] U.S. Congress, House, Armed Services Committee, Hearings on the Department of Defense Authorization for Appropriations for Fiscal Year 1981, 96th Cong., 2nd sess., 1980, p. 834.

capability and, although the manufacturing processes are designed to accommodate that rate, the excess capacity is to be held in reserve.

One of the obstacles associated with raising the rate of production has been the ability of the government to afford facilities. An $811 million facilitization program was planned using an inflation rate of about 5.5%. Higher actual inflation effectively reduced the amount available and delayed facilitization.

There was some skepticism in the M-1 government program office that unit costs would continue to decrease with rates above the level of about 90 per month. Based on their experience with the M-60 tank, it was thought that second shift inefficiencies would raise unit cost. It was acknowledged, however, that fixed overhead cost to the program would be reduced with increasing rate. General Babers, in testimony before Congress, stated his belief that overall cost would continue to be reduced as the production rate approached 150 per month.[19] Since then however, affordability considerations have limited the maximum total production capacity to 90 units per month which is now considered the Economic Production/Procurement Rate.

The rates and costs used to derive the curve are as shown in Table A-1. Costs are in millions of current year dollars.

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[19] Ibid., p. 835.

Table A-1. Production Rates and Costs.

FY*	79	80	81	82	83	84	85
Yearly Quantity	90	309	569	665	776	720	720
Manuf. Cost	80.9	239.3	421.1	462.4	562.4	559.3	638.6

FY*	86	87
Yearly Quantity	720	720
Manuf. Cost	680	724.3

* 79-81 rates and costs are actual. All other costs are estimated.

Future Production Rate. At the time of this writing (November 1982) funds to support the future production schedule of the M-1 were being debated in the Congress and there was no firm schedule. The most likely rate is 60 per month until the total quantity of 7,058 tanks is reached.

A-3. Findings

Using the data above in the Bemis model, multiple regression analysis gave the following equation:

$$UC = 2.9827\ Q^{-0.05160}\ R^{-0.1475}$$

and:

$$r = 0.9893 \qquad R^2 = 0.9787$$

This corresponds to an improvement curve slope of 96.5% and a rate slope of 90.3%. The effect of rate is greater than the effect of quantity.

Total manufacturing cost for production from FY 84 to the end (total quantity of 7058) was calculated using the PESO "POM 84" computer program, for four production schedules with the results as shown below (an inflation rate of 6.6% was used for FY 84 and 6.5% was used for all other years):

A. FY 84-89: 60/month or 720/year

FY 90: 329/year

total manufacturing cost in FY 83 $ = 3,433M

total manufacturing cost in current dollars = 4,380M

average unit cost in FY 83 $ = 0.738M

average unit cost in current $ = 0.942M

B. FY 84-87: 90/month or 1080/year

FY 88: 329/year

total manufacturing cost in FY 83 $ = 3,249M

total manufacturing cost in current $ = 3,863M

average unit cost in FY 83 $ = 0.699M

average unit cost in current $ = 0.831M

C. FY 84: 90/month or 1080/year

FY 85-86: 120/month or 1440/year

FY 87: 689/year

total manufacturing cost in FY 83 $ = 3,157M

total manufacturing cost in current \$ = 3,674M

average unit cost in FY 83 \$ = 0.679M

average unit cost in current \$ = 0.790M

D. FY 84: 90/month or 1080/year

FY 85: 150/month or 1800/year

FY 86: 1769/year

total manufacturing cost in FY 83 \$ = 3,032M

total manufacturing cost in current \$ = 3,471M

average unit cost in FY 83 \$ = 0.652M

average unit cost in current \$ = 0.747M

A-4. Analysis of Findings

Bemis model estimates of savings in manufacturing costs by increasing the production rate from 60/month to higher levels are shown below:

Maximum Production Rate	Total Cost Savings: FY 84 - end (Compared to Cost at 60/month) FY 83 \$	Current \$
90/month	184M	517M
120/month	276M	706M
150/month	401M	909M

There were insufficient data to use other models. However, General Babers in congressional testimony[20] estimated a total program cost reduction of $412.2 million by increasing the rate of production to 90/month.

Figure A-1 shows the isocost and rate analysis. Compared with the "rolling ball path," the actual rate increase path is very good until 60/month is reached. The figure shows that the isocost lines are cut more quickly by continuing to increase the production rate as before, rather than leveling off at 60/month.

A-5. Conclusion

The M-1 program has a short production history from which to draw conclusions. For the regression analysis, historical data are preferred over predicted data. For this program, a number of predicted costs were used in the model, but these were confined largely to a single rate of 60/month and any distortion they may cause was kept to a minimum.

The program has followed a relatively efficient path during the build up phase of production. The graph and the equation show that the program is "rate favored" and therefore unit cost should drop significantly with increasing rate of production.

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[20] Ibid., p. 856.

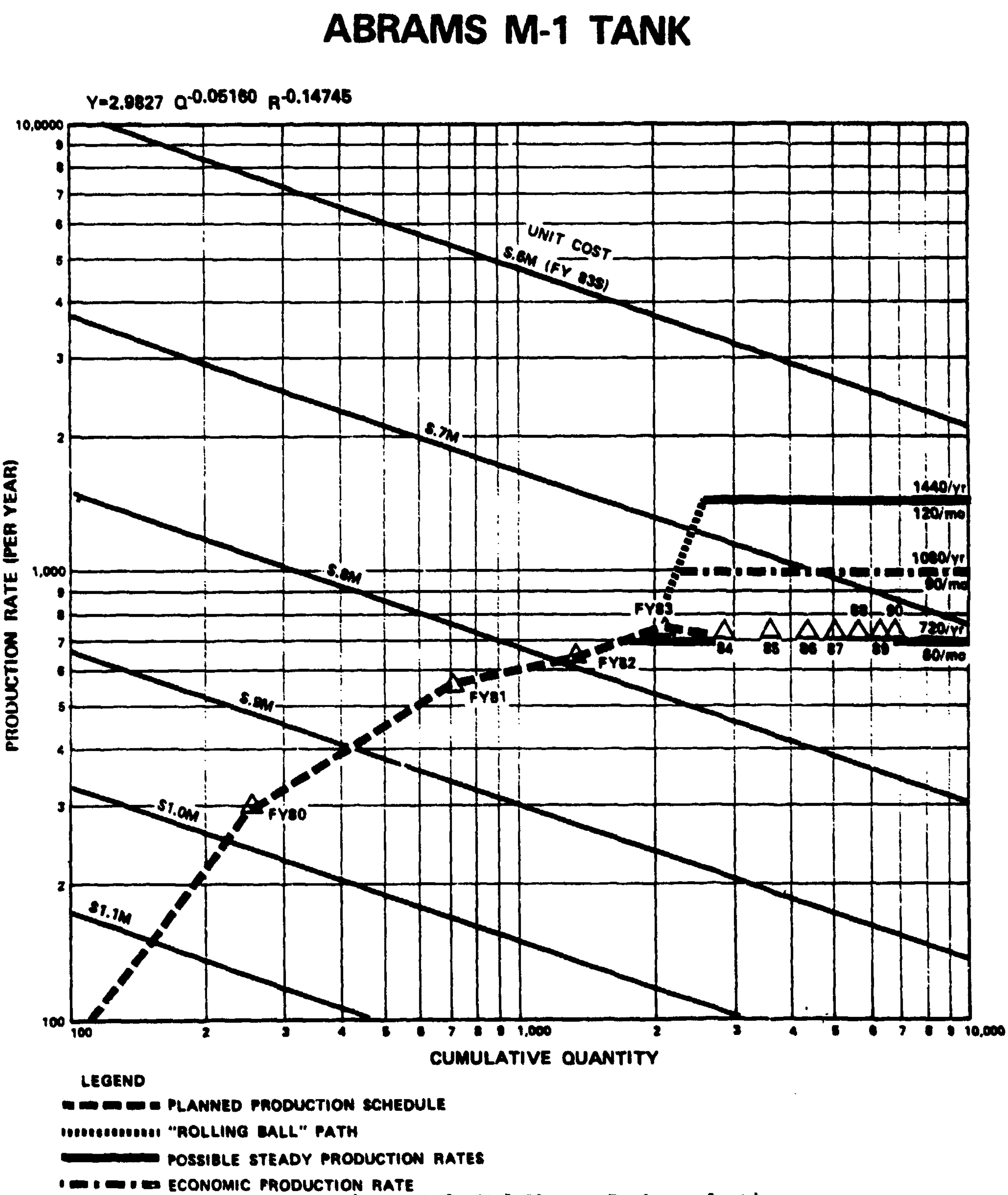

Figure A-1 M-1 Abrams Tank Production Rate vs. Cumulative Quantity

It is important to note that the M-1 production facilities are government-owned and contractor-operated; therefore, much of the fixed overhead costs will continue after the M-1 program is completed. If the facilities cannot be used or sold after the completion of the M-1 program, the constant dollar costs to the government will not be reduced.

BRADLEY FIGHTING VEHICLE SYSTEM ANNEX

B-1. General Background and Data Sources

There are two versions of this system: a Cavalry Fighting Vehicle and an Infantry Fighting Vehicle. For the purposes of this study the differences are negligible and were ignored. The Fighting Vehicle System (FVS) carrier has also been selected as the transporter for the multiple launch rocket system (MLRS); however, any cost advantage due to quantity or rate based on the MLRS was unknown and not considered in this study.

There are several major subcontractors involved in producing the FVS beside the prime contractor, FMC. Those considered in the study are Hughes Aircraft for the TOW, General Electric for the transmission and turret control, and Cummings for the engine. It was considered necessary in the study of this program to include the major subcontractors, since their share of the cost is approximately equal to that of FMC.

The data used in the study was from the government program office and provided by the Office of the Deputy Chief of Staff, Research, Development and Acquisition (ODCSRDA). Although the quantities are out of date, they do agree with the costs and were used in the regression analysis to arrive at the unit cost-cumulative quantity-rate equation. The data is dated 18 January 1982 and is in escalated dollars. Only the sum of all contractor costs is provided here, since that is the basis for this analysis.

FY	80	81	82	83	84
Quantity	100	400	600	600	555
Cost (Esc. M$)	105.6	380.8	543.5	623.1	584.6

FY (Cont'd)	85	86	87	88	89
Quantity	775	1009	958	1080	512
Cost (Esc. M$)	838.9	1069.4	1058	1247.1	979.5

The cost/quantity figures above were used to calculate the generalized equation from the Bemis model. It is not necessary that the quantity figures be the latest planning figures in order to do this calculation only that the cost and quantity association be valid.

B-2. Production Rate

The latest information available showed the schedule to be as follows:

FY	80	81	82	83	84
Quantity	100	400	600	600	600

FY (Cont'd)	85	86	87	88	89
Quantity	830	1080	1080	1080	805

The economic production rate is presently 1080 items per year.

B-3. Findings

Using the Bemis model, regression analysis yielded the following equation for the Fighting Vehicle System:

$$UC = 2.578\, Q^{-.10372}\, R^{-.04195} \quad (FY\ 83\$)$$

where:

UC = manufacturer's unit cost of the Qth item produced at rate R

Coefficient of multiple correlation (r) = .97195

Coefficient of multiple determination (R^2) = .94469

Slope of improvement curve = 93.1%

Slope of rate curve = 97.1%

Here the effect of quantity is greater than the effect of rate.

A plot of the planned production rate and isocost lines is shown in Figure B-1.

B-4. Analysis of Findings

A comparison of the plot of the planned production schedule with the isocost lines and "rollirg ball path" in Figure B-1 shows a good build up during FY 80-82. A plateau of 600/year is held until FY 84, after which the production rate rises to 1080/year in 1986.

The build up in production rate is efficient until the plateau at 600/year is reached. For a more economical production schedule, it would be best to continue the increase in rate, rather than have a pause in production. Costs for both alternatives, as predicted by the model, are shown below. The initial production of 1100 systems during the period FY 80-82 is considered common to both alternatives and is therefore omitted from both.

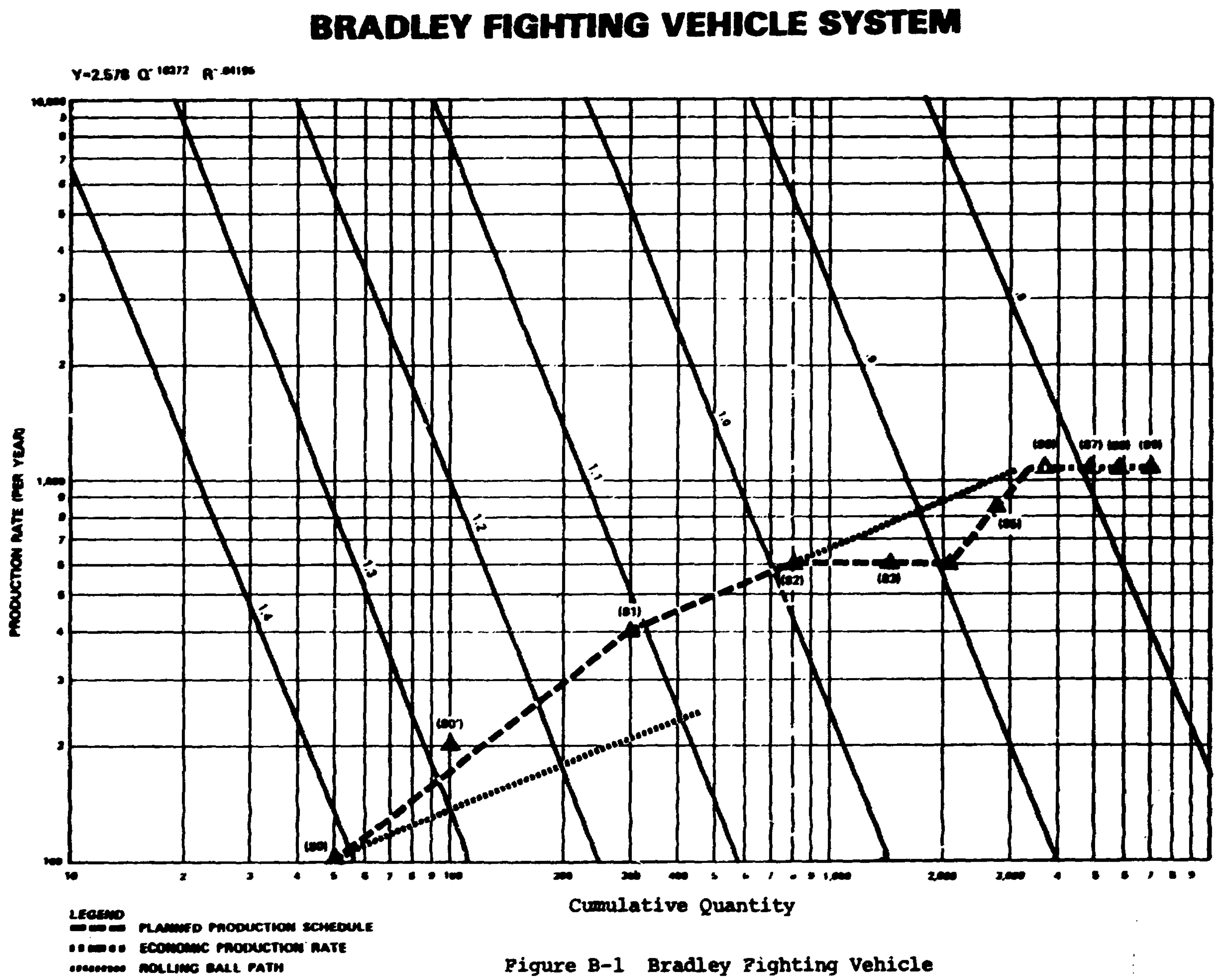

Figure B-1 Bradley Fighting Vehicle
Systems Production Rate vs. Cumulative Quantity

Planned Production Rate FY 83 - end (a total of6075 units)

Note: 1100 units were produced previously

FY	83	84	85	86	87	88	89
Quantity	600	600	830	1080	1080	1080	805

The above figures and the generalized equation from the Bemis model were input to the DoD Product Engineering Support Office (PESO) POM-84 computer program and the summary figures below were generated. To use the program it was necessary to deflate the prime unit cost from 2.578 (FY 83) to 2.403 (FY 82). The summary figures below are, therefore, in FY 82 dollars.

Cost in FY 82 $ (M) = 4689

Cost in escalated $ (M) = 6179

Average manufacturing unit cost in FY 82 $ (M) = 0.772

Average manufacturing unit cost in escalated $ (M) = 1.017

Economic Production Rate FY 83 - end (a total of 6075 units)

Note: 1100 units were produced previously

FY	83	84	85	86	87	88	89
Quantity	750	900	1000	1080	1080	1080	185

Cost in FY 82 $ (M) = 4678

Cost in escalated $ (M) = 5972

Average manufacturing unit cost in FY 82 $ (M) = 0.770

Estimated savings:

FY 82 $ (M) = 4689 - 4678 = 11M

Current $ (M) = 6179 - 5972 = 207M

B-5. Conclusions

Because of inflation (9% planned; 12% actual) and limitations attributable to full-funding requirements, the program suffered a setback by having the first year of production reduced from 208 to 100. Figure B-1 shows that if production in the first year had remained 208 as planned for (point 80', Figure B-1), the build up rate would have approximated the "rolling ball path" from 1980 to 1981.

A return to the "rolling ball path" during FY 83-86 would save the program an estimated $11M (FY 82 dollars) or $207M (current dollars). Two factors are responsible for the relatively small size of these figures. First, the program is "cumulative quantity favored" and is relatively less sensitive to changes in production rate then quantity. Second, the program has a good build-up path, except for the plateau at 600/year.

A-10 AIRCRAFT ANNEX

C-1. General Background and Data Sources

The A-10 is a twin-turbofan aircraft specifically designed to provide an air support capability composed of close supporting fire, armed escort, and armed reconnaissance. The A-10 was produced by Fairchild Industries using a Fixed Price Incentive Fee type contract from FY 75 through FY 79. Since FY 79, the A-10 has been procured using a Firm Fixed Price Contract.

The primary data for the A-10 was taken from information acquired from the Aeronautical Systems Division (ASD) Cost Library at Wright-Patterson Air Force Base (WPAFB), Ohio. The data was confirmed by ASD and A-10 program office personnel.

The primary data from the ASD Cost Library was the A-10 DD Form 1558-4 Cost Information Report as of 30 September 1981. This was the latest DD Form 1558-4 on the A-10 program. The report, as of 30 September 1982, will be published in December 1982. The Contractor Cost Data Report (CCDR) replaces the DD Form 1558-4. The DD Form 1558-4 shows the FY program by quantity, engineering, tooling, quality control, manufacturing, purchased equipment, material overhead, subcontract, other items not shown elsewhere, and total cost less General and Administrative. The engineering, tooling, quality control and manufacturing categories were further broken into direct labor hours, direct labor dollars, overhead, materials and other direct charges. The DD Form 1558-4 provided

manufacturing and overhead costs. The manufacturing costs were used in the Bemis model. Contractor manufacturing costs are considered the best cost information upon which to base the cumulative quantity, unit cost, and procurement rate analysis. The availability of overhead cost data on the A-10 was a bonus that enabled us to also use the C.H. Smith Model. However, the DD Form 1558-4 does not separate overhead into its fixed and variable components. Therefore, we took the total overhead costs and plotted them on a scatter diagram in which the dependent variable (y axis) is overhead cost and the independent variable (x axis) is the number of items (A-10s) procured per year. We performed a regression analysis and developed a linear equation as the best fit of the data. The linear equation was a straight line of the form $y = mx + b$, where m is the slope of the total overhead line and b is the y intercept. The y intercept is also the fixed overhead cost per year. This fixed overhead cost was used in the C.H. Smith model to enhance our analysis of the A-10 procurement rate.

The other important ASD Cost Library data source was the A-10 Cost Management Review (as of 31 December 1981),[21] which was based on the analysis of A-10 Selected Acquisition Reports (SAR). This review provided a comprehensive and accurate account of how and why the cost to the A-10 program changed since the estimate for full-scale development was approved by the Deputy Secretary of Defense in May 1973.

[21] Aeronautical Systems Division, Air Force Systems Command, "A-10 Cost Management Review," ASD Cost Library, Wright Patterson AFB, Ohio, 31 December 1981.

The Air Force Systems Command's Aircraft Acquisition Program Cost Summary, Part II provided current cost data as of 3 December 1981. This data include an FY 82 buy, but no FY 83 buy. This data provided total procurement costs of $4572.3 million (current year dollars).

The ASD and A-10 program personnel provided valuable information in addition to validating the information we gathered from other sources. Examples of information they provided are the A-10 procurement delivery schedule and insight concerning the Economic Procurement Rate (EPR).

C-2. Procurement Rate

Economic Procurement Rate. The original Development Estimate (DE)[22] was prepared on the assumption that the A-10 could be procured within an average unit flyaway cost of $1.5 million (1970 $), if 600 units were procured at a rate of 20 per month; however, based on the recommendation of the Office of the Secretary of Defense (OSD) Cost Analysis Improvement Group (CAIG),[23] the Deputy Secretary of Defense directed that the DE be revised upward to make it consistent with an average unit flyaway cost of $1.7 million (1970 $). The A-10 production was never facilitized to produce at a rate of more than 12 aircraft per month because of affordability constraints. Therefore, the EPR was 12 A-10s per month.

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[22] Ibid., p. 2.

[23] Ibid., p. 2.

Actual Procurement Rate. All cost figures in this section are in constant FY 70 dollars. The actual procurement rate for the A-10 resulted from a mixture of program changes directed by Congress, OSD and the Air Force. Changes resulted in a net real program cost growth of $593.7 million between June 1973 and December 1981, based on the program that includes an FY 83 buy. These changes started in September 1973 when the Senate Armed Services Committee directed the Air Force to conduct a flyoff between the A-7D and A-10.[24] This was done from 15 April through 9 May 1974 at Fort Riley, Kansas. An independent analysis of data accumulated during the flyoff by the Weapons System Evaluation Group confirmed the Air Force finding that the A-10 performed better and was more cost effective than the A-7D.[25] However, the time required to complete this action caused a slowdown in the then approved A-10 development program. The impact of this Congressionally directed A-7/A-10 flyoff and the transfer of the Engine Component Improvement Program to RDT&E caused a total RDT&E program cost increase in December 1973 of $23.3 million. Also, in December 1973 $5.1 million user funding was directed to be sent to the test centers that increased the program support cost by that amount.

An adjustment was made in the program in March 1974 as the result of revising the cost estimating methodology. This adjustment reduced the program's estimated procurement cost by $20.6 million.

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[24] U.S. Congress, Senate, Armed Services Committee, quoted in Aeronautical Systems Division, "A-10 Cost Management Review," p. 2.

[25] Aeronautical Systems Division, "A-10 Cost Management Review," pp. 4-7.

The A-10 program was restructured in July 1974 to reflect Congressional denial of FY 74 advanced procurement funds and direction to transfer four DT&E aircraft from RDT&E to procurement funding. The revised program also reflected an increase from 18 months to 20 months for the FY 76 buy of long lead items. The RDT&E budgetary impact to the program of the Congressional funding reduction was recorded in December 1973 as $6.8 million. The deletion of four RDT&E aircraft in September 1974 had a RDT&E budgetary impact of plus $0.7 million. Procurement cost increases due to schedule that resulted from these actions included $10.5 million because of the schedule slip and $1.8 million because of a higher learning curve position caused by the reduced RDT&E quantity of aircraft.

The A-10 program was further restructured in November 1974 after Congress reduced the FY 75 funds. The FY 75 buy was changed to 22 and the deliveries were stretched out to reflect a slower buildup to the rate goal of 20 aircraft per month. These budgetary constraints increased the program in December 1975 by $273.2 million.

The FY 77 budget contained a maximum rate of 15 aircraft per month with procurement ending in FY 80. Budget constraints imposed during the preparation of the FY 78 budget resulted in the reduction of the FY 78 buy year procurement quantity from 173 to 144 aircraft and slipped final procurement to FY 81. This reduction resulted in a rate of 12 aircraft per month. This was the rate at which the program was facilitized to produce and represents the EPR.

In June 1978 the SAR reflected an increase of $8.8 million for the Congressionally imposed addition to the A-10 of an Inertial Navigation System (INS).

Congressional action on the FY 79 President's Budget reduced the FY 79 buy from 162 to 144 aircraft. This FY 79 reduction and resulting schedule stretch out imposed by Congress was shown in the December 1978 SAR as a program cost increase of $25.3 million.

The FY 81 program was reduced from 106 to 60 aircraft in the FY 81 President's Budget. This FY 81 reduction and schedule stretch directed by OSD resulted in a program cost increase in December 1979 of $40.0 million. At this time 46 aircraft per fiscal year were added in FY 82 through FY 84, increasing total program quantity by 92 aircraft. The schedule component of cost increase of 92 additional aircraft was $110.4 million. The additional 92 aircraft also increased quantity procurement costs by $105.9 million.

The FY 82 President's Budget terminated the program in FY 81 by deleting 138 aircraft for a total buy of 687 aircraft. The amended FY 82 President's Budget added 60 aircraft in FY 82 for a total of 747. The FY 82 Amended President's Budget was revised in October 1982 by deleting 20 of the 60 FY 82 aircraft and deferring 6 A-10A and 14 A-10B aircraft to FY 83. The production and delivery schedule were changed from 5 per month to 3 per month. This restructure produced an FY 82 advanced procurement requirement for which funds were not authorized, but were appropriated. The OSD-directed deletion of 20 aircraft in FY 82, and deferment of 20 aircraft to

FY 83, caused a net increase in the program of $11.2 million. This included increased cost because of lower procurement rate (+$43.8 million) and decreased costs because of the reduced quantity (-$32.6 million). Congress cancelled the FY 83 procurement request for 20 A-10s, thus terminating the total Air Force A-10 program at 707 aircraft.

In addition to the above Congressional- and OSD-directed program changes, the Air Force made decisions that caused changes in cost. The Air Force decisions resulted in a net real cost decrease of $8.7 million, by reducing the 825 aircraft program (as described in the FY 81 President's Budget) by 98 aircraft in the FY 82 revised Amended President's Budget and reductions due to escalation and funds withdrawals. Program quantity decreases offset cost increases due to avionics enhancements and additions to support equipment and spares.

The net impact of Congressional, OSD, and Air Force directed cost changes was a program cost increase of $593.7 million based on the program with a FY 83 buy of 20 aircraft. This program shows rate reductions from the planning rate of 20 to 15 and then from 15 to 12 (EPR rate facilitized to) to 5 in FY 81 and finally to 3 aircraft per month in FY 82. The amount of increased procurement cost attributed to lower production rate from the facilitized EPR of 12 A-10s per month to 5 and below was $43.8 million. However, Congress cut the program without the FY 83 buy of 20 aircraft.

C-3. Findings

Bemis Model results for the A-10. The data for the A-10 aircraft was input to the Bemis PESO multiregression model after conversion of the A-10 unit cost from current to FY 83 constant dollars (used as a baseline for this research study). The Bemis PESO model was run using the methodology explained in the general body of this report to obtain the following equation: $UC = 11.08\ Q^{-.1610}\ R^{-.0342}$. The coefficient of multiple correlation (r) is 0.96 and the coefficient of multiple determination (R^2) is 0.92. This means that 92 percent of the variation of the unit cost is explained by variation of the independent variables cumulative quantity and rate of production. Table C-1 shows the actual A-10 aircraft FY procurement quantities (FY 75 through FY 81), manufacturing unit cost (FY 83 constant dollars), and the program quantity that would have been produced at the EPR of 12 per year. The FY 82 buy quantity was not used to derive the A-10 curve because there was no manufacturing cost data available for FY 82. The 20 aircraft programmed for FY 82 bring the total to the correct quantity of 707 A-10s to be procured.

Table C-1. A-10 Manufacturing Unit Cost.

	FY 75	FY 76*	FY 7T*	FY 77	FY 78	FY 79	FY 80	FY 81	Total
Actual Qtys	22	30	43	100	144	144	144	60	687**
Manufacturing*** Unit Cost	7.601	5.040	4.549	4.017	3.854	3.565	3.544	3.5	
Program Qty**** at EPR	22	30	43	100	144	144	144	80	707

Notes:

* The FY 76 and FY 7T period of 15 months was divided by the A-10 Program Office into A and B procurements that resulted in two equal delivery periods. In the chart the FY 76 represents the A and FY 7T represents the B procurement quantities.

** The 687 total does not include the FY 82 buy of 20 aircraft.

*** The unit cost is in millions of FY 83 constant dollars.

**** The EPR quantity includes the FY 82 buy of 20 aircraft.

C.H. Smith Model results. We derived the fixed overhead cost using linear regression analysis and the procedure described under General Background and Data Sources. We found the y intercept or fixed overhead cost to be $46.4 million per year in FY 83 constant dollars. The coefficient of correlation (r) is .935 and R^2 is .874. This means that 87.4 percent of the variation of the overhead cost is explained by the independent variable (the number of A-10s produced per year). Procurement at the EPR rate permits completion of procurement of the current program total of 707 aircraft in approximately seven months after the start of the FY 80 delivery period, versus at the end of the FY 82 delivery period as it is in the actual program. The government will pay for the total fixed overhead for FY 81. Thus, the EPR program saves one year of fixed overhead costs or (1

year) x ($46.4 million/year) = $46.4 million. These results were based on the program through FY 82. If Congress had not terminated the program without the FY 83 buy the government would have paid for two years of fixed overhead or $92.8 million (FY 83 constant $).

Cost comparison results for the A-10. These results were derived using the Bemis model. Table C-2 shows the comparison of total procurement cost in constant and current year dollars for the program at the actual and EPR rates:

Table C-2. A-10 Procurement Costs.
(Dollars in millions rounded to nearest tenth)

	FY 75	FY 76	FY 7T	FY 77	FY 78	FY 79	FY 80	FY 81	FY 82	Total
Actual Program										
Actual Rate	22	30	43	100	144	144	144	60	20	707
Total Cost										
(Constant FY 83 $)	158.9	166.3	210.3	426.4	548.8	511.3	486.9	203.3	69.7	2781.9
(Current dollars)	81.1	90.5	122.9	253.7	356.4	366.0	385.1	175.4	64.9	1896.0
EPR Program										
EPR	22	30	43	100	144	144	144	80		707
Total Cost										
(Constant FY 83 $)	158.9	166.3	210.3	426.4	548.8	511.3	486.9	271.1	0	2780.0
(Current dollars)	81.1	90.5	122.9	253.7	356.4	366.0	385.1	233.9	0	1889.6

C-4. Analysis of Findings

The data sources indicated that 20 A-10s per month was the planned EPR. The House Armed Services Committee hearing testimony on the FY 77

Budget recorded a rate of 20 A-10s per month at a design-to-cost goal for the unit flyaway cost of $1.5 million per aircraft, based on a total procurement of 600.[26] This confirms the ASD Cost Library data.[27] The HASC record also stated that early production readiness reviews showed Fairchild Republic Corporation (FRC) might have had difficulty producing at the 20 per month rate;[28] however, a special review in late 1974 concluded that FRC could have produced at that rate and that earlier deficiencies had been corrected. Another review in September 1975, this time by the Air Force, concluded a rate of 20 aircraft per month was possible and that FRC could meet the RDT&E and production delivery dates then set for the program.[29] The first aircraft of the 22 FY 75 production lot was delivered in November 1975.[30]

The rate of 20 aircraft per month was the planned procurement rate for the program until the FY 77 budget. The record of the HASC Hearing on the FY 77 Budget states that there was a program budget decision to cut the maximum rate from 20 to 15 per month and stretch out the program.[31] The reason given was budget constraints, or, in other words, because of affordability concerns. The FY 78 program was cut during budget preparation from

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[26] U.S. Congress, House, Armed Services Committee, Hearings on the Department of Defense Authorization for Appropriations for Fiscal Year 1977, 94th Cong., 2nd sess., 1976, p. 216.

[27] Aeronautical Systems Division, "A-10 Cost Management Review," p. 3.

[28] U.S. Congress, House, Armed Services Committee, Hearings on the Department of Defense Authorization for Appropriations for Fiscal Year 1977, 94th Cong., 2nd sess., 1976, p. 217.

[29] Ibid., p. 217.

[30] Ibid., p. 206.

[31] Ibid., p. 216

173 to 144, or a rate of 12 per month because of affordability. Again, in FY 79 the quantity was cut from 162 to 144, or a rate of 12 per month, also because of affordability. The program produced at this reduced rate of 12 per month through FY 80. However, the 12 per month rate was the level to which the production line was facilitized and therefore represents the SPR for the program. The rate of 12 per month was on a 2-8-5 shift basis, i.e., 2 shifts of 8 hours per day for 5 days a week. The reductions in FY 81 and beyond are explained under Actual Procurement Rate. These final decreases in rate were again caused by affordability. The increased procurement cost to the total program due to these decreases in procurement rate was recorded in the A-10 Cost Management Review as $43.8 million in FY 70 dollars ($115.5 million in FY 83 dollars).[32] This figure was based on the program that had an FY 83 buy of 20 aircraft. The FY 83 buy was cut by Congress. Thus, one of the years at the very low rate of procurement of 3 aircraft per month was avoided.

FRC won the contract for the T-46A (Next Generation Trainer). FRC plans to apply lessons learned from the production of the A-10 to the T-46A program. The trainer program could be worth between $1.5 billion to $2 billion to FRC ultimately, but production is not scheduled to begin until 1986. The loss of funding for the A-10 in the FY 83 Budget leaves FRC with little production base. Foreign Military Sales (FMS) could help this situation, but none have been ordered, although many FMS customers have considered buying the A-10.

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[32] Aeronautical Systems Division, "A-10 Cost Management Review," Table 3, p. 10.

Looking at the program year procurements at a constant EPR of 12 aircraft per month, vice the actual program, provides the quantity differences shown in Table C-3.

Table C-3. A-10 Procurement Rates.

	FY 75	FY 76	FY 7T	FY 77	FY 78	FY 79	FY 80	FY 81	FY 82	Total
Actual Rate:	22	30	43	100	144	144	144	60	20	707
EPR:	22	30	43	100	144	144	144	80	0	707
Difference	0	0	0	0	0	0	0	-20	20	0

It is obvious that procurement of the A-10 at the EPR would have concluded the program a little over one year earlier than the actual completion, and a little over two years earlier than the program with the FY 83 buy (which was eliminated by Congress).

The total procurement cost for the EPR program (Table C-2) in FY 83 constant dollars would be $2780.0 million, and in current dollars would be $1889.6 million. The total procurement cost for the actual program in FY 83 constant dollars would be $2781.9 million, and in current dollars would be $1896.0 million. Therefore, the savings of the EPR program over the actual program for the same total procurement of 707 aircraft in FY 83 constant dollars would be $1.9 million, or, in current year dollars, $6.4 million. The savings are insignificant in FY 83 constant dollars, based on the analysis using the Bemis model.

This study compared the cost savings (in FY 83 constant dollars) that would result from producing at the EPR versus actual rate using two

methods: 1) the Bemis model and 2) the C.H. Smith model. This study also compared results with the A-10 Cost Management Review that determined the costs that were attributed to the reduction in rate.[33] The results were not directly comparable because the Bemis and C.H. Smith Models were based on DD Form 1558-4 FRC manufacturing costs only, and the A-10 Cost Management Review was based on total program costs as recorded in the SARs through 31 December 1981. Also the A-10 Cost Management Review was based on a program with an FY 83 buy and the Bemis and C.H. Smith models were based on a program with FY 82 procurement. An attempt was made to establish a common baseline by comparing airframe costs taken from the DD Form 1558-4 and the Air Force Systems Command's (AFSC) Aircraft Acquisition Program Cost Summary, Part II. The total procurement airframe flyaway cost recorded in the AFSC's Aircraft Acquisition Program Cost Summary, Part II, as of 3 December 1981 in current year dollars, excluding the FY 83 buy, was $3844.6 million. This is the closest figure to manufacturing airframe costs available, excluding DD Form 1558-4 data. The airframe manufacturing cost in current year dollars based on DD Form 1558-4 data was $1896.0. Thus, $3844.6 million (total procurement flyaway cost) divided by $1896.0 million (airframe manufacturing cost) results in a factor of two. Multiplying this factor by the cost savings derived from the Bemis model gives $3.8 million (FY83 constant dollars), vice $1.9 million. Multiplying this factor by the cost savings from the C.H. Smith model gives $92.8 million, vice $46.4 million. The final comparison is shown in Table C-4.

[33] Ibid., p. 10.

Table C-4. Cost Attributed To Change In Rate.

(Millions of FY 83 Constant Dollars)

Bemis Model	4.6*
C.B. Smith Model	92.8*
A-10 Cost Management Review Data	115.5**

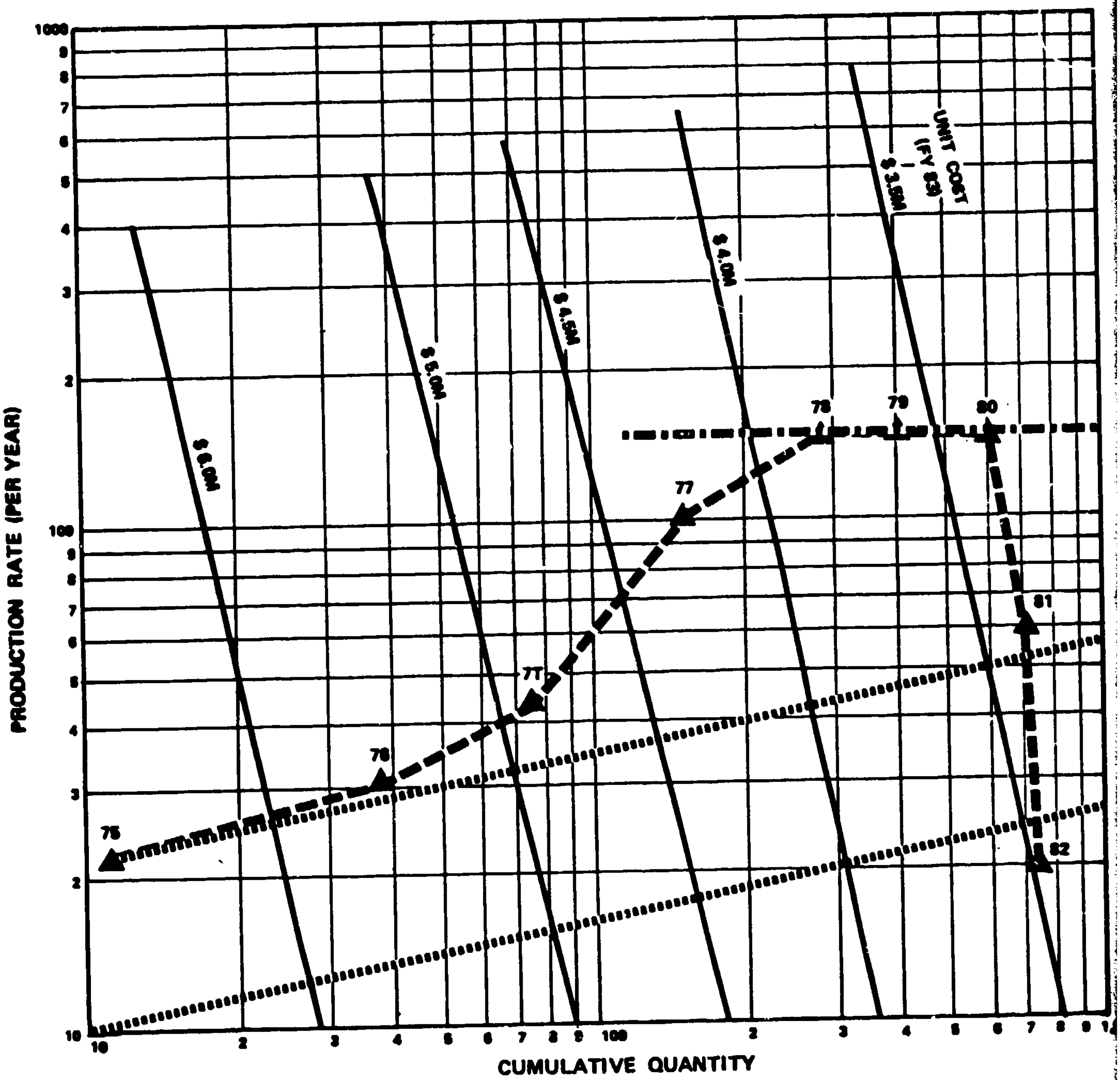
* Based on the A-10 program through FY82.

** Based on the A-10 program through FY83. Although we were unable to determine the cost associated with a year of production at 3 aircraft per month, had the FY 83 buy been allowed by Congress, we conclude that the $115.5 million would be reduced.

Figure C-1 shows a plot of Production Rate vs. Cumulative Quantity vs. Unit Cost. The slope of the "rolling ball" line is important. One line is drawn from the origin with a parallel line in the family of lines plotted starting at a rate of 22 aircraft per month. The gradual slope of the rolling ball plot reflects the fact that cumulative quantity has a greater effect on unit cost than rate does. The path of the rolling ball cuts isocost lines perpendicularly. Isocost lines are drawn at $6.5, $6, $5, $4.5, $4 and $3.5 million. The actual A-10 program is plotted from FY 75 through FY 82 for comparison.

The slope of the rolling ball path and the actual program are identical through the FY 76 program. The actual program line diverges from the rolling ball line more steeply for FY 7T and more steeply yet for FY 77. This is good from a cost standpoint. For example, for FY 77 the approximate unit cost of 200 aircraft is about $4.1 million in the actual program, versus about $4.25 million on the rolling ball line. The actual program

A-10



LEGEND

PLANNED PRODUCTION SCHEDULE

"ROLLING BALL" PATH

POSSIBLE STEADY PRODUCTION RATES

ECONOMIC PRODUCTION RATE

Figure C-1. A-10 Production Rate vs. Cumulative Quantity.

procurement rate continues to increase at a slope greater than the rolling ball line slope. The slope of a family of rolling ball lines in the A-10 program, based on the equation derived from the historical manufacturing cost of the actual program, is very shallow. This means the effect of change in rate is relatively less important than the effect of cumulative quantity for this program. This is probably caused by the fact that the rate of production of 12 aircraft per month was the facilitized rate. Consequently, if the government for some reason chose to extend this program at a low procurement rate to keep a warm base (e.g., to keep the production line open until FMS customers materialize, if mobilization is required, or to keep the FRC A-10 production team together until T-46A procurement begins), the slope of the rolling ball path indicates this is a viable alternative for this program. However, the analysis shows that if the rates of procurement below 12 aircraft per month continued they would result in unit cost increases.

C-5. Findings and Conclusions

- The EPR for the A-10 was 12 aircraft per month on a 2-8-5 shift basis. FRC was facilitized at this rate.

- Budget constraints and affordability concerns reduced the program from a planned rate of 20 aircraft per month to the EPR. The program was able to absorb affordability reductions without a cost impact because the level of facilitization was consummate with the rate attained (12 aircraft per month). The first cut was from a planned but never attained rate of 20 to 15 aircraft per month. The next cut was from 15 to 12 aircraft per

month, which was the facilitized EPR at which the A-10 was manufactured for the three primary producing years of the program. The final years of procurement were also impacted by affordability constraints and the rate was reduced to 5, and then to 3 aircraft per month. The program was terminated by Congress without an FY 83 buy.

- The equation for the A-10 program shows a change in rate being relatively less important than cumulative quantity. We believe this is due to the fact that the program was facilitized at the lower rate. A program with these characteristics is one for which a decision to stretch the program at a reduced procurement rate is a viable alternative.

- Analysis using the Bemis model shows that had procurement been completed at the EPR, versus the actual rate, there would have been an insignificant savings of $1.9 million (FY 83 dollars).

- Analysis using the C.H. Smith model shows a potential savings of fixed overhead cost of $92.8 million (FY 83 dollars), or a little over 3 percent of the total program manufacturing costs expressed in FY 83 constant dollars.

- Analysis of the A-10 Cost Management Review shows a cost increase to the program due to rate reduction of $115.5 million (FY 83 dollars), or a little over 4 percent of the total procurement program expressed in FY 83 constant dollars. This

is based on a program with an FY 83 buy. This figure would he reduced because Congress terminated the program at the end of FY 82.

- The C.H. Smith model shows a more significant cost savings than the Bemis model. The cost attributed to rate changes recorded in the A-10 Cost Management Review would probably approximate those of the C.H. Smith model after the cost savings due to rate associated with the FY 83 buy (that was not allowed by Congress) is factored in.

- The C.H. Smith model can be used only if the government has access to fixed overhead data from the contractor.

- There is no apparent potential for FMS for the A-10.

TOW MISSILE ANNEX

D-1. General Background and Data Sources

TOW (Tube Launched, Optically Tracked, Wire Command Link Guided Missile System) is designed to fulfill the heavy antitank assault weapon system requirement. TOW is used primarily to destroy formations of armored vehicles, but is also an effective assault weapon against vehicles, field fortifications, and emplacements. TOW has a 4-man crew and can be fired either from a ground tripod or from specifically adapted vehicles. TOW has also been designated as the point target weapon on selected helicopters.

The TOW program was selected for this study because of its long procurement history and the relatively large total procurement quantity at a high production rate.

The procurement and missile unit cost data for the TOW system were taken from ODCSRDA historical records. The records consisted of Congressional Data Sheets and budget backup exhibits (P-Forms) for the FY 75 through FY 82 President's Budgets. Specific exhibits (P-Forms) examined were the TOW System Program Summaries, the Budget Item Justification Sheets (Exhibit P-40), Missile Cost Analysis (Exhibit P-12) and the Production Schedules (Exhibit P-21). The other data source was the Research Development Acquisition Committee (RDAC) Procurement Worksheet dated 2 April 1976. They provided U.S. Army, U.S. Marine Corps (USMC) and foreign military sales (FMS) quantities of basic TOW missiles procured from the beginning of the program through the FY 79 buy. The basic TOW missile,

hereafter referred to as the TOW I missile, includes both TOW High Energy Anti-Tank (HEAT) and practice missiles. Their unit cost is derived from the annual total procurement cost of the missiles (HEAT and practice) divided by the quantity of U.S. Army missiles to be procured in that FY. This unit cost for TOW I missiles takes into consideration the economies gained through total sales to all customers. The USMC and FMS requirements significantly increased the total quantity of missiles procured.

The TOW II production cost estimate was based on TOW I production experience and facilitization. Much of the TOW II missile is physically the same as the TOW I missile. The only major improvements are a larger warhead configured with a stand-off probe, and an improved beacon, to improve electro-optical counter-countermeasures. Therefore, TOW I missile production experience can be applied to TOW II. John M. Cockerham & Associates, Inc. estimated the TOW II rate curve slope at 94 percent,[34] based on TOW II contract proposal data. This correlates well with our historical data. The ODCSRDA data result in a cumulative quantity cost improvement curve slope of 92 percent and a rate slope of 95.5 percent.

D-2. Procurement Rate

Economic Procurement Rate. The planned procurement rate for the TOW I missile as recorded in Exhibit P-21 supporting the FY 75 President's

[34] Walter Batson, John M. Cockerham & Associates, Inc., interview at MICOM, Redstone Arsenal, Alabama, 7 and 8 October 1982.

Budget was projected at 1500 per month from November 1972 through October 1973, the delivery period for the FY 72 TOW I program. The procurement rate increased from 1500 per month to 2000 per month during the delivery period for the FY 73 program from November 1973 through October 1974. TOW I missile procurement was scheduled to reach the facilitized and planned Economic Procurement Rate (EPR) in March 1975 and continue at that EPR of 3450 missiles thereafter. The TOW I missile program procurement rates recorded in the RDAC Work sheet dated 2 April 1976 were:

Minimum Sustaining Rate = 1000 missiles/month.

1-8-5* Facilitized Rate = 1800 missiles/month.

2-8-5 Economic Production Rate = 3500 missiles/month or 42,000 missiles/year.

*1-8-5 means 1 shift of 8 hours per day for 5 days per week. This may include a second shift to augment some manufacturing stations.

The total production rate capacity for all TOW configurations is 3500 missiles/month. TOW II only is 2500 missiles/month based on current facilitization of tools and test equipment.

Actual Procurement Rate. TOW I missiles were procured using multi-year Fixed Price with Escalation (FPE) contracts renegotiated annually. These contracts had options that, when executed, increased the quantities to be produced. They provided flexibility to meet additional U.S. Army, USMC, and FMS customer requirements and at the same time kept the procure

ment rate as close to the EPR as possible. Production Schedule (Exhibit P-21) dated 13 September 1976 shows deliveries fluctuating near the 3500 missile/month rate from 1975 through March 1978, which marks the end of the FY7T deliveries and the beginning of the FY 77 delivery period. The FY 77 program deliveries were at rates that started above, but dipped below, the minimum sustaining rate recorded in the RDAC Worksheet dated 2 April 1976. U.S. Army procurement was for only 5720 TOW missiles in FY77. The contractor had to rely on USMC and FMS requirements to keep the production rate at the minimum level. The Army could not make up its mind on the best means to satisfy the heavy antitank missile requirements in response to an increasing enemy armor threat. Alternatives to improve TOW I performance included either various modifications to the TOW I missile or a new system development. The modification program included considerable development time and money, but could be done more quickly than the development of a new system. Also, TOW I missiles were needed to replace those expended during training. These events, augmented with FMS requirements, provided some justification for maintaining a warm production base for the TOW I missile until TOW II missiles could be delivered.

All procurements of TOW missiles beginning with FY 80 are for improved type II missiles that would defeat the advanced armor threat.

The production line for TOW II is similar to TOW I; however, additional automation and modified tooling was added to improve production based on lessons learned and to support the new missile design.[35] The U.S.

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[35] Ibid.

Army total quantity requirement for the TOW II missile has not been determined. However, plans recorded in the Budget Item Justification Sheet (Exhibit P-40) in support of the FY 82 President's Budget dated 15 September 1980 are to procure the TOW II missile, to satisfy Army requirements, at a rate of 1000 missiles per month. The TOW program office expects sufficient FMS and other sales to increase the rate to the EPR of 3500 missiles per month.

D-3. Findings

Bemis model results for the TOW missile. The data for the TOW I missile was input to the Bemis multiregression model after conversion of the missile unit cost from current to FY 83 constant dollars (used as a baseline for this research study). The Bemis model was run using the methodology explained in the general body of this report to obtain the following equation: $y=50.25\ Q^{-0.1198}\ R^{-0.0656}$. The multiple correlation factor (r) is 0.93 and coefficient of multiple determination (R^2) is 0.865. This means that 86.5 percent of the variation of the unit cost is explained by the variation of the independent variables of cumulative quantity and rate of production. Table D-1 shows the actual TOW I missile FY procurement quantities by customer (FY 72 and prior through FY 79), procurement unit costs by FY (current dollars), and the program quantities that could have been produced at the EPR.

Table D-1. TOW I Procurement.

	FY 72 & Prior	FY 73	FY 74	FY 75	FY 76	FY 7T	FY 77	FY 78	FY 79
Qtys* USA	43635	12000	18000	23860	23813	1922	5720	5720	9600
USMC			5425	6319	498	890	7331	6541	
FMS	6500	9743	10972	25673	10403	7261	7356	24748	7962
USN									1320
GA**								1388	1397
MAP***							1420		
Payback									113
Total	50135	21743	34397	55852	34714	10073	21827	38397	20392
Missile**** Unit Cost	5.91	3.04	3.190	3.023	3.304	3.434	4.181	3.581	4.292
Program Qty at EPR	50135	21743	42000	42000	42000	10500	42000	37152	

Notes: Total Missiles procured through FY 79 = 287530

* Includes HEAT and Practice Missiles
** Government Assistance (GA)
*** Military Assistance Program (MAP)
**** Unit Cost in Thousands of Current Year Dollars

C.H. Smith Model Results. We did not have fixed cost data on TOW I needed to use the C.H. Smith Model.

Cost Comparison Results For The TOW I Missile. These results were obtained using the Bemis model. Table D-2 shows the comparison of total procurement cost in constant and current year dollars for the program at the actual and EPR rates:

Table D-2. TOW I Costs (Actual vs. EPR).

	FY 73	FY 74	FY 75	FY 76	FY 7T	FY 77	FY 78	FY 79	Total
Actual Program*									
Actual Rate**	21743	34397	55852	34714	10073	21827	38397	20392	287530***
Total Cost :									
(Constant FY 83 $)	151.8	222.8	333.7	206.5	64.1	130.8	218.3	119.2	1447.2
(Current $)	163.4	256.2	409.5	271.2	85.6	190.3	349.5	211.1	1936.8
EPR Program*									
EPR**	21743	42000	42000	42000	10500	42000	37152		287530***
Total Cost :									
(Constant FY 83 $)	151.8	267.2	255.4	247.2	66.5	239.6	209.6		1437.3
(Current $)	163.4	307.4	313.4	324.6	88.9	348.8	335.6		1882.1

* All dollars are in Millions (rounded to nearest tenth of million)
** The Actual and EPR quantities and rates through FY73 and the build-up period are the same
*** Includes FY72 and prior quantity of 50135

D-4. Analysis of Findings

The data indicate the U.S. Army purchased 144,270 TOW missiles or 50 percent of the total, the USMC purchased 28,324 TOW I missiles or 10 percent, and foreign customers purchased 113,936 TOW I missiles or 40 percent of the total 286,530 TOW I missiles procured from the start of the program through FY 79. Foreign customers accounted for 23 percent of the

total procurement in FY 73 and prior, 32 percent in FY 74, 46 percent in FY 75, 30 percent in FY 76, 72 percent in FY 7T, 34 percent in FY 77, 64 percent in FY 78 and 46 percent in FY 79. The TOW I missile actual deliveries to all customers were at or near the EPR of 3500 missiles per month. This was because of FMS. In the years when the Army was marking time considering alternatives for improving or replacing TOW I, the FMS were helpful in maintaining a warm base at a unit cost that remained relatively economical for the Army in spite of the Army's small requirement. The FMS requirements allowed the contractor to maintain a relatively stable delivery rate of around 3500 missiles per month through the end of the FY 7T delivery period on 31 March 1978. A comparison of the program year procurements at a constant EPR of 42,000 missiles per year, with the actual program, provides the quantity differences shown in Table D-3.

Table D-3. TOW I Actual Procurement Rates vs. EPR.

	FY 74	FY 75	FY 76	FY 7T	FY 77	FY 78	FY 79
Actual Rate:	34397	55852	34714	10073	21827	38397	20392
EPR:	42000	42000	42000	10500	42000	37152	0
Difference	-7603	13852	-7286	-427	-20173	1245	20392

Notes:
- FY 73 and prior rates are the same because both built toward the same EPR.
- The EPR allows the program quantity of 286530 to be bought out in FY 78 with a last year buy of 37152.

A comparison of the FY 74 through FY 7T EPR with the actual program rates shows a difference of only 1464 TOW missiles. FY 77 through FY 79 annual quantities fall below the EPR rate.

The total procurement cost for the EPR program taken from Table D-2 in FY 83 constant dollars is $1437.3 million, and in current dollars is $1882.1 million. The total procurement cost for the actual program in FY 83 constant dollars is $1447.2 million, and in current dollars is $1936.8 million. Therefore, the savings of the EPR program over the actual program for the same number of total TOW missiles in FY 83 constant dollars is $9.9 million, and in current year dollars is $54.7 million. Although there are savings (less than 1 percent), they are relatively small compared with the total program procurement cost of approximately $1.5 billion in FY 83 constant dollars.

Figure D-1 is a plot of the actual and economic production rates based on the Bemis theory. The path of the rolling ball cuts the isocost lines perpendicularly. Isocost lines are drawn at $7, $6.5, $6, $5.5 and $5 thousand. The actual program moves more steeply than the EPR path from the $7 to the $6 thousand isocost lines. In FY 76, the rate drops below the EPR line. As described earlier, the FY 76 and 7T delivery periods were at the EPR. The unit cost of just under $6 thousand is maintained from FY 75 to FY 77. FY 78 shows the effect of increased rate and quantity because of FMS increases that help lower the unit cost to approximately $5.7 thousand per missile. The unit cost increases to approximately $5.8 thousand in FY 79, largely because of a decrease in rates. The U.S. Army requirements for FY 77, FY 78 and FY 79 were, respectively, 5720, 5720, and 9600 missiles. The lack of FMS in FY 77 and 79 decreased the rate. The unit cost increase is predictable with these changes.

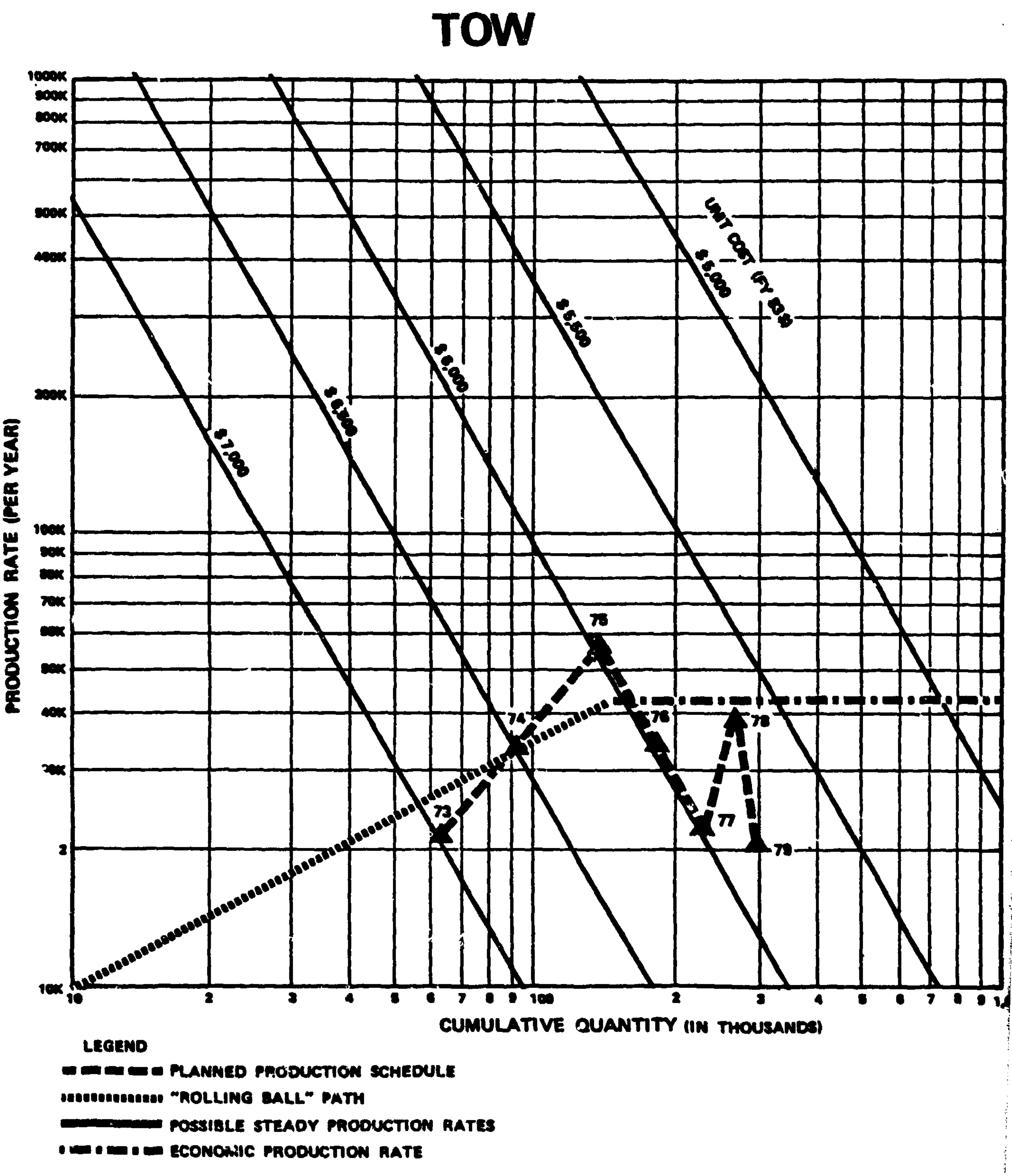

Figure D-1. TOW Missile Production Rate vs. Cumulative Quantity.

The TOW II procurement, a product improved TOW I missile, is underway. The Army can request procurement funds for TOW II missiles based only on Army requirements. The FY84 Army requirement is for 12,000 TOW II missiles. The current USMC requirement is for 1000 TOW II missiles/year. The Army FY85 requirement is 18,000 TOW II missiles and increases to 20,000/year through FY 89. Contract options have been negotiated that can accommodate additional Army and USMC requirements and FMS. FMS interest is high and approval is being sought to sell TOW II missiles to foreign countries.[36]

D-5. Findings and Conclusions

- The TOW missile program for all customers achieved procurement at the EPR through the end of the three month fiscal year (FY 7T) delivery period. The FY 77 through 79 program years had minimum sustaining TOW missile quantities because the Army did not know how to proceed to meet the increased armor threat requirements. The procurement rates for FY 77-79 fell far below the EPR and were it not for USMC and FMS requirements, keeping a warm production base would have been impossible.

- The actual TOW missile procurem[illegible] was maintained at the EPR because of the USMC and large FMS requirements in addition to

[36]TOW Program Office Representative, interview at the Defense Systems Management College, Ft. Belvoir, Virginia, 14 December 1982.

the U.S. Army requirements. There were also contract options that allowed a flexible approach for including FMS customer requirements as they became firm.

- The total procurement cost savings, although relatively insignificant, would have accrued from maintaining the EPR throughout the TOW missile program.

- There are many considerations in addition to maintaining the EPR that affect the quantity and rate of procurement. Examples are fielding schedules, support equipment, shelf life of the missiles, and the rate of procurement and fielding of other systems upon which the TOW system is deployed.

- The TOW II is sufficiently similar to the TOW I missile, so that the lessons learned from TOW missile procurement are directly applicable to the TOW II program.

- The TOW II missile EPR should be the same as the TOW I missile EPR; that is, 3500 missiles per month, or 42,000 missiles per year.

- Multiyear contracting is being pursued with the TOW II system.

A-6E AIRCRAFT ANNEX

E-1. General Background and Data Sources

The A-6 Intruder developed by Grumman Aerospace Corporation is an all-weather attack aircraft whose mission is the destruction of enemy sea and land targets with conventional or nuclear weapons without visual reference to the targets. The A-6E series is a much improved version that began production in 1970. This series is equipped with an inertial navigation system and a much improved radar, which provide a more accurate bombing system. Current versions are equipped with the electro-optical Target Recognition Attack Multisensor (TRAM), which includes a forward-looking infrared receiver (FLIR), a laser designator, and a laser ranger.

The A-6 went into production in 1959. By 1969, 488 units were delivered. The A-6E series was begun in 1970, and 153 units have been produced. Projections are for 6 a year until 1987, when production will cease; however, no replacement aircraft is yet planned.

Quantities of aircraft and unit cost data were received from the Naval Air Systems Command (NAVAIR) Program Office (PMA-234) and from the Cost Analysis Division (NAVAIR-524). There are slight differences in the two sets of data.

E-2. Production Rate

Economic Procurement Rate

The economic procurement rate (EPR) for the A-6E is given by the manufacturer as 36 to 48 aircraft per year, and 24 units for the EA-6B, with which the A-6 shares the production line.[37] Together, then, the two planes would have a combined EPR of 60 to 72 units per year; however, this is also dependent on the rate for the F-14, which is parallel to the A-6E/EA-6B production line. The upper limit of 48 for the A-6E is also constrained by the A-6E TRAM Detecting and Ranging System (DRS) avionics, which is developed by Hughes Aircraft. Hughes cannot build more than 4 units per month, unless additional tooling is provided.[38] The main landing gear is another constraint. The maximum A-6/EA-6 main landing gear cylinder casting/machinery rate is a function of the overall DOD aircraft procurement rate, since there are only two or three companies available.[39]

NAVAIR is keeping the production line open in order to replace aircraft lost through attrition (until an all-weather replacement aircraft is identified), and to provide an umbrella over the TRAM MOD and re-wing programs. Nevertheless, NAVAIR recognizes that keeping the production line open "is not optimum from a unit cost standpoint."[40]

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[37] Naval Air Systems Command, "Uneconomic Production Rates," Washington, DC; AIR-8012:STS, 22 May 1981, enclosure 2, p. 1.

[38] Ibid., p. 1.

[39] Ibid., p. 1.

[40] Ibid., p. 1.

Actual Production Rates

Grumman Aerospace Corporation designed, developed, and has manufactured the A-6 since 1959. The A-6A was produced from 1959 to 1969. Production of the A-6E began in 1970 and is expected to continue until 1987. Actual rates are shown in Table E-1.

Table E-1. A-6 Yearly Procurement Quantities.

A-6A	
1959	8
1961	12
1962	24
1963	43
1964	48
1965	64
1966	112
1967	63
1968	78
1969	36
	488

A-6E	
1970	12
1971	12
1972	12
1973	21
1974	13
1975	12
1976	11
1977	6
1978	12
1979	12
1980	6
1981	12
1982	12
	153

A total of 641 A-6A and A-6E aircraft have been procured. Future rates of A-6E production are projected at 6 per year until 1987. There were unnecessary breaks in A-6E production in 1977 and in 1980, both of which caused discontinuity and resulted in significant increases in unit cost after production was resumed.

E-3. Findings

Regression analysis was used to develop equations relating the A-6's costs, production rates, and cumulative quantity. The equation for the production of only the A-6A is:

$$UC = 109.325\ Q^{-.3241}\ R^{-.2320}$$

The coefficient of multiple correlation (r) is .962. The coefficient of multiple determination (R^2) is .925. This means that 92.5% of the variation in unit cost for the A-6A is explained by variation of the independent variables of cumulative quantity and rate of production. The exponent for cumulative quantity (-0.3241) equates to an improvement curve slope of 79.8%. This means that every time the A-6A cumulative quantity doubled, the unit cost decreased by 20.2%. The exponent for the rate of production (-0.2320) equates to a slope of 85.2%.

The A-6E unit costs followed a typical "sawtooth" pattern caused by the two production breaks. A model was developed as shown in Figure E-1.

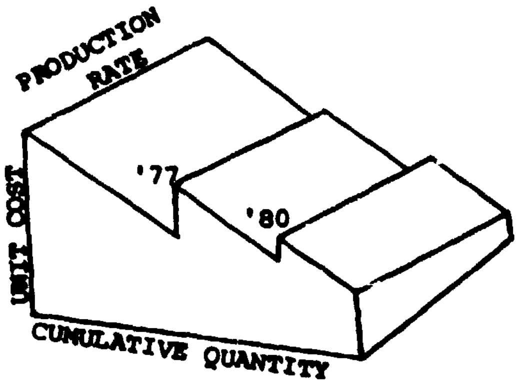


Figure E-1. Three-Dimensional Model Showing Unit Cost Changes Due To Production Breaks.

The rate and quantity exponents were determined from the unit costs during the FY 70 through FY 76. The coefficient or "prime" unit cost (comparable to first unit cost on an improvement curve) was derived from FY 82 data. The resulting equation (in FY 83 dollars) for the A-6E is:

$$UC = 31.9833\ Q^{-0.0913}\ R^{-0.2422} \quad (\text{FY 83 \$})$$

The coefficient of multiple correlation (r) is .915. The coefficient of multiple determination (R^2) is .837. The exponent for cumulative quantity (-0.0913) equates to a 93.9% A-6E improvement curve slope. The exponent for the rate of production curve (-0.2422) equates to a slope of 84.5%.

The unit costs and yearly procurement quantities are shown in Table E-2.

Table E-2. A-6A Production Quantities and Costs.
($ in Millions)

	Yearly Quantity	Unit Cost (FY 83 dollars)
1959	8	63.473
1961	12	19.389
1962	24	14.741
1963	43	9.764
1964	48	8.795
1965	64	7.934
1966	112	6.819
1967	63	6.435
1968	78	6.575
1969	36	6.833

The costs and quantities of the actual past and projected A-6E production are shown on the left of Table E-3. If the program were procured at the economic production rate of 48 aircraft per year, then the costs would be those shown on the right. As can be seen in the table, the entire program would have been procured by 1973.

Table E-3. A-6E Production Quantities and Costs.
($ in Millions)

	ACTUAL AND PROJECTED			EPR		
	YEARLY QUANTITY	UNIT COSTS (FY 83 $)	TOTAL (FY 83 $)	YEARLY QUANTITY	UNIT COSTS (FY 83$)	TOTAL (FY 83 $)
1970	12	10.492	125.901	48	8.154*	391.331*
1971	12	9.618	115.418	48	7.153*	343.340*
1972	12	9.415	112.979	48	6.817*	327.289*
1973	21	7.914	166.190	39	6.969*	271.730*
1974	13	6.909	89.811			
**1975	12	8.397	100.763			
1976	11	8.838	97.213			
1977	6	12.163	72.978			
1978	12	8.947	107.368			
1979	12	9.295	111.544			
**1980	6***	13.882	83.292			
1981	12	11.802	141.623			
1982	12	11.111	133.333			
1983	6	11.010*	66.060*			
1984	6	10.973*	65.838*			
1985	6	10.936*	65.616*			
1986	6	10.901*	65.406*			
1987	6	10.868*	65.208*			
Totals	183		$1,786.541	183		$1,333.690

* Derived using PESO's "POM 84" model.
** Major configuration change.
*** Latest figures indicate 8 aircraft will be procured in FY 83. This would increase savings approximately $8M (2 x 11.010 - 2 x 6.969).

E-4. Analysis of Findings

Table E-4 compares the A-6A slopes for rate and cumulative quantity (improvement) curves with those for the A-6E.

Table E-4. A-6 Production Curve Slopes.

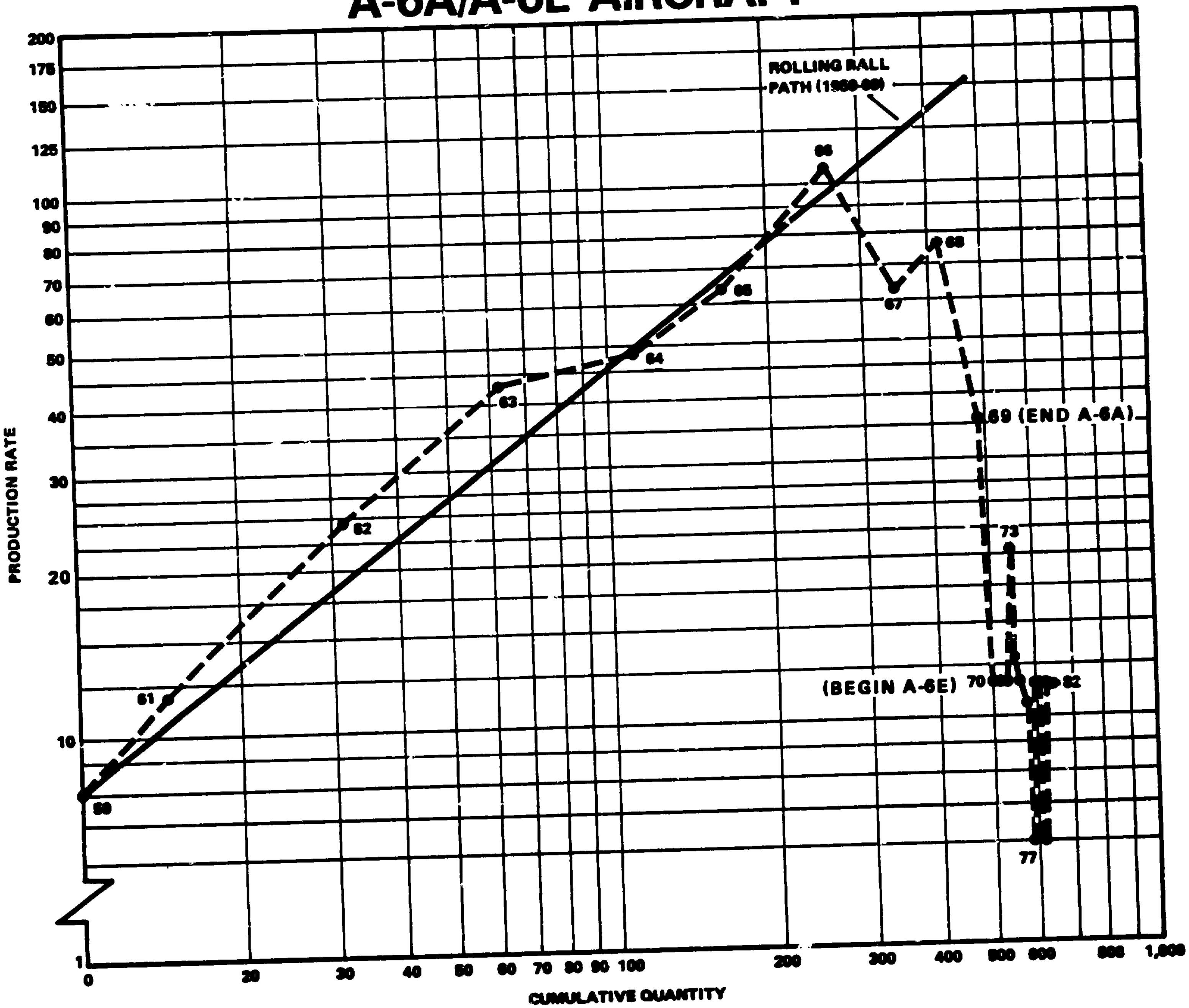
A-6A	Q	79.8%	A-6E	Q	93.9%
	R	85.2%		R	84.5%

If the cumulative quantity factor "Q" is a function of variable costs and the rate factor "R" is a function of fixed costs (see Section 3.3), the figures in Table E-4 imply that the fixed costs for the two systems have remained approximately the same. Unit costs for the A-6E would then have risen as the yearly procurement quantity decreased. This is supported by Figure E-2, which graphically displays the dramatic reduction in the A-6E production rate.

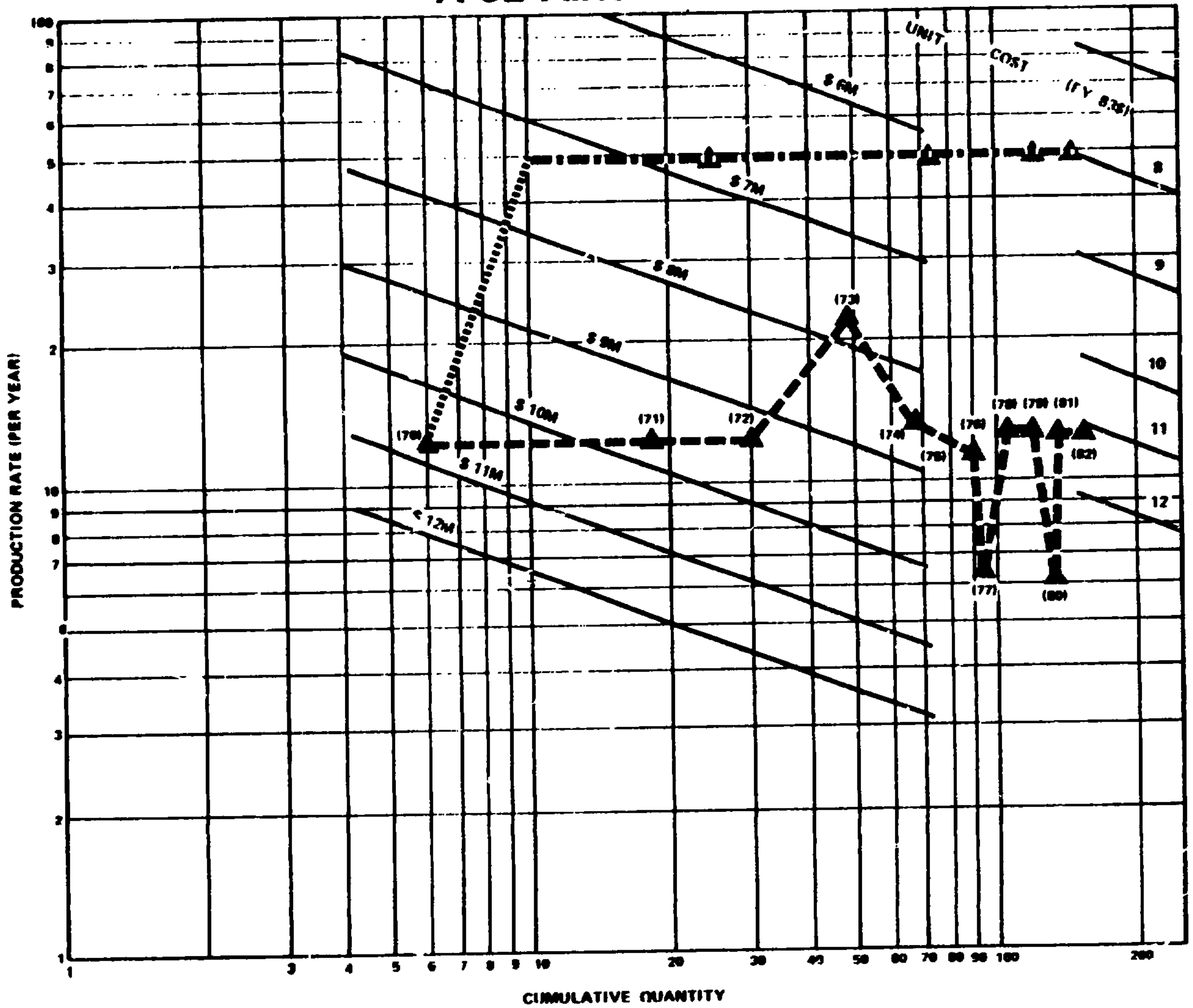
A plot of the A-6E isocost lines is shown in Figure E-3. It is apparent that the aircraft could have been procured at a much reduced cost if it had been procured at a higher rate.

If the A-6E had been procured at a rate of 48 per year, all 183 units would have been produced in 3½ years with an approximate savings of $461M (FY 83).

A-6A/A-6E AIRCRAFT



A-6E AIRCRAFT



LEGEND

PLANNED PRODUCTION SCHEDULE

"ROLLING BALL" PATH

ECONOMIC PRODUCTION RATE

GAP IN UNIT ISOCOST LINES DUE TO PRODUCTION HALTS

FIGURE E-3 A-6E PRODUCTION RATES VS. CUMULATIVE QUANTITY

Figure E-3 shows a dashed line that is perpendicular to the isocost lines. This is the "rolling ball" path for the A-6E. A build up at that rate would have been a cost efficient path to the EPR of 48 units/year.

The isocost lines indicate that the unit costs at the EPR would have been substantially less than the actual costs.

E-5. Arguments For Low Rate A-6E Production

Among the arguments offered for having stretched out the A-6E production are:

1. It was more economical to modify existing aircraft on the production line than off. The government program office estimates that these savings outweigh the savings that would have been achieved by a production rate of 48 per year.

2. It is necessary to maintain a warm base until production begins on a follow-on all weather attack aircraft.

E-6. Conclusions

- Had the total number of aircraft needed been known in 1970, the A-6E costs could have been reduced by more than $460 million (FY 83 dollars) by producing at the EPR.

- Available data suggest that costs can be reduced by as much as \$75 million (FY 83 dollars) by producing the remaining planned 24 A-6E aircraft (FY 84-87) in one year.

- Unit costs can be reduced by eliminating some fixed overhead costs through selling or reallocating excess industrial resources.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER MDA 903-82-G-0051.82-4.0002	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Economic Production Rate Study	5. TYPE OF REPORT & PERIOD COVERED 1 July 1982 - 15 March 1983
	6. PERFORMING ORG. REPORT NUMBER ADTECH Report No. 31413.02
7. AUTHOR(s) Downing, E.J.; Roesler, G.E.; McGovern, W.M.	8. CONTRACT OR GRANT NUMBER(s) MDA 903-82-G-0051.82-4.0002 Task Order No. 82-4
9. PERFORMING ORGANIZATION NAME AND ADDRESS Advanced Technology, Inc. Airport Plaza, Suite 500 2711 Jefferson Davis Hwy, Arlington, VA 22202	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS David D. Acker Defense Systems Management College Ft. Belvoir, VA 22060	12. REPORT DATE 15 March 1983
	13. NUMBER OF PAGES 112
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release. Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for public release. Distribution unlimited.

18. SUPPLEMENTARY NOTES

N/A

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

EPR, production, unit cost, program stability, acquisition, defense acquisition management, economic production rate, economic procurement rate, A-10 Aircraft, A-6E Aircraft, TOW Missile, Abrams M-1 Tank, Bradley Fighting Vehicle System.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report defines and discusses economic production rate and economic procurement rate. Examples are presented to clarify the definition. Models are presented which relate changes in unit cost to changes in production rate. The procurement rates of five defense acquisition programs are analyzed with respect to their economic procurement rates.

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)